THE OUTLINE OF KNOWLEDGE

EDITED BY

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GEOLOGY

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BIOLOGY

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ZOOLOGY

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GEOLOGY

CHAPTER I

MYTHS OF THE EARTH'S ORIGIN

THIS Earth whereon man lives, by which he has his being and to which he returns, was to the ancients a riddle inexplicable. What mighty hand, they wondered, could have upreared the mountain peaks whose glittering summits pierced the very clouds; what fearsome figure lurked in the volcanic forge where subterranean rumblings seemed to tell of life within; what stupendous power could evoke from nowhere the shrieking tempest which destructively could mock the puny efforts of the world of men? Answers there must be, and the beginnings of Geology are the cosmogonies devised by inexact observation and by fancy to propound a suitable reply.

The earliest efforts at the interpretation of nature found their expression in the mythologies and cosmogonies of primitive peoples, which varied in type from country to country, according to the climate and other physical conditions under which they had their birth. Geological speculation may thus be said to be traceable in the mental conceptions of the remotest pre-scientific ages.

Among these first gropings after truth the Babylonian account of the Creation holds an honored place, not only by reason of its completeness, but also because modern knowledge of it is gained from tablets of extreme antiquity, tablets which in themselves hold high rank in the records of historical importance. With the Babylonians Creation begins with Chaos. The gods arose before heaven and earth had taken shape, while the tumultuous floods of oceans were still intermingled in the universal chaos. The gods chose Marduk to be their champion against Tiamat, the disturbing, chaotic ocean-flood. Marduk armed himself with lightning flash and thunderbolt and called the winds to his assistance. Marduk vanquished Tiamat and divided his corpse into two parts; from the one part he created the heavens and from the other the earth and the sea. Marduk peopled the heavens with stars, the dwellings of the great gods. Then followed the creation of plants and animals and finally the creation of the two first human beings out of clay.

The Mosaic account of the Creation far excels the Babylonian in its noble simplicity and in the strength and beauty of the language. In it the origin of the world, of the earth and its inhabitants, is represented as the work of a personal God. The Mosaic account, which is especially distinguishable among early cosmogonies by its recognition of the existence of light before the actual orb of the Sun was visible (due to dense aqueous atmosphere) was incorporated in the Bible of the Christian Church, and, unfortunately, was regarded as being a scientific treatise, in addition to its recognized character as a statement of Creation designed to teach Man about his origin and his personal relations to his Creator. This misconception of the purpose of the early chapters of the Book of Genesis retarded the progress of Geology for many centuries, as theologians sought to suppress all scientific centuries, as theologians sought to suppress scientific writings which did not harmonize with their interpretation.

The Greeks were less inclined than the Oriental nations to interweave the ideas of mythology, religion and science. They viewed natural events from a more critical standpoint and treated them as subjects of philosophical speculation. In their early Ionian days, however, their understanding of the cosmogony was comparatively primitive, tho heightened and made of interest by the imaginative force with which they peopled that portion of the Earth's surface which was remote to them.

Homer's contributions to ancient geography were large—and curious, but cosmogonical ideas do not seem to have occurred to him. He presupposed that the earth was flat, and that the sun truly sank into the sea. Hesiod, in his "Theogony," tells of the birth of the world and Time "Chronos," he describes the wars of the older and the Olympian gods, but he seems to have accepted the prevalent conception of the world as a flat disk with Greece in the center.

These early cosmogonies, while differing greatly in style, elaboration of detail and the degree to which they expressed the conceit of the author, had certain points in common. They all agree on successive alternate creations and destructions of the world. These speculations were closely interwoven with their religion, as were all the sciences, and the destructions were supposed to come when man's sin had become intolerable to the then ruling deity. The following creation included a race of men free from sin and taint of all kinds, who immediately proceeded to gradually degenerate. In the "Institutes of Menu," the sacred volume of the Hindus, is the following verse:

> "There are creations also and destruction of worlds innumerable.

The Being, supremely exalted, performs all this with as much ease as if in sport, again and again, for the sake of conferring happiness."

"There are at the same time such puerile conceits and monstrous absurdities in this cosmogony," says Sir Charles Lyell in his famous "Principles of Geology," "that some may be disposed to impute to mere accident any slight approximation to truth or apparent coincidence between the Oriental dogmas and observed facts. This pretended revelation, however, was not purely an effort of the unassisted imagination nor invented without regard to the opinions and observations of naturalists. There are introduced into it certain astronomical theories, evidently derived from observation and reasoning. Thus, for instance, it is declared that, at the North Pole, the year was divided into a long day and night and that their long day was the northern, and their night the southern course of the Sun; and to the inhabitants of the Moon, it is said, one day is equal in length to one month of mortals."

The Brahmins and Chinese corroborated this notion of successive creations and destructions and also described a great flood. Plutarch tells us that this was the subject of one of the famous hymns of Orpheus. In his verses he sets a definite period for each cycle or life of a world. Orpheus assigned 120,000 years while Cassandra took it to be 360,000 years.

The Egyptian priests were aware not only that the soil beneath the plains of the Nile, but that also the hills bounding the great valley, contained marine shells, and it could hardly have escaped the observation of Eastern philosophers that some soils were filled with fossil remains, since so many national works requiring extensive excavations were executed by Oriental monarchs in very remote eras.

Thales of Miletus, the contemporary of Crœsus and Cyrus, who considered that everything, animate and inanimate, was derived from water, added but little to early cosmology, save that his theory presupposed a condition of constant flux. His gifted scholar, Anaximander (circa 611 B.C.), arrived at a higher conception of Nature. He depicted an infinite, all-pervading primeval substance, possessing an inherent power of movement from the first. The energy of this primeval matter determined heat and cold, and the mixture of these conditions gave origin to the development of fluid; the earth, the air and a surrounding circle of fire differentiated from the fluid state. The stars sprang from fire and air; the earth rested in the center of the whole universe, and, under the influence of the sun, brought forth the animals which inhabited it. These, including human beings, were at first fish-like in form, consistent with the semi-fluid state of their environment.

Xenophanes of Colophon (614 B.C.) is reported by later writers to have observed the shell remains of pelagic mollusca on mountains in the middle of the land, impressions of laurel leaves in the rocks of Paros, as well as various evidences of the former presence of sea on the ground of Malta, and to have attributed those appearances to periodic invasions of the sea during which men and their dwellings must have been submerged. The historian Xanthus of Sardis (circa 500 B.C.) also drew attention to the occurrence of fossil shells in Armenia, Phrygia and Lydia, far from the sea, and concluded that the localities where such remains occur had been formerly the bed of the ocean and that the limits of the dry land and the ocean were constantly undergoing change.

Herodotus (484 B.C.) mentioned the presence of fossil shells of marine bivalves in the mountains of Egypt and near the oasis of Ammon. From this fact, as well as from the salt constitution of the rocks, Herodotus formed the opinion that Lower Egypt had been at one time covered by the sea, and that the material carried down by the Nile had been discharged into the sea-basin between Thebes and Memphis and the present delta, and gradually filled it up. Herodotus could not form any definite opinion as to the cause of the Nile inundations, altho he gave a careful report of the hypotheses then in favor.

The Gorge of Tempe, previously referred to, also came under the notice of the Father of History. He says:

> "That the Gorge of Tempe was caused by Poseidon is probable; at least one who attributes earthquakes and chasms to that god would say that this gorge was his work. It seemed to me to be quite evident that the mountains had there been torn asunder by an earthquake."

Heraclitus (535 B.C.) thought there was in the universe nothing stable, nothing lasting. Everything was in a state of constant change, like a stream in which new waves endlessly supplant the old. For him fire was the primeval force, which unceasingly transformed itself, pervaded every portion of the universe, produced individuals and again destroyed them. Fire became the ocean, and that again earth, and the breath of life. The rising vapors burned in the air and formed the sun, which was renewed from day to day. Thus Heraclitus taught that altho the universe always had been and always would be, no portion of it had ever been quiescent, and that from time to time a new world was constructed out of the old.

Pythagoras, who was born at Samos about the year 582 B.C., and afterward went to Crotona in Italy, is one of those eminent leaders of thought around whose name and teaching much that is mythical has gathered. "His followers," suggests Karl von Zittel in his "History of Geology and Paleontology," sought to explain natural phenomena chiefly by analogy with definite numerical relationships. An ordered universe depended, according to the Phythagoreans, upon the principle of numbers. According to Diogenes Laertius, Pythagoras imagined the universe in the form of a sphere. The earth was in the center and bore the axis around which the firmament revolved."

The principle of constant change taught by Phythagoras and Heraclitus was also a leading feature in the doctrines of Empedocles of Agrigentum (492-432 B.C.). Empedocles supposed that everything had its origin in, and took its components from, four elements (earth, water, air and fire); that these elements were without beginning and imperishable, but subject to never-ending change. From these elements the world at one time took shape, and it must at some future time be again dispersed. The course of the world's existence resolved itself into a history of recurring periods and phases. Geology owes one distinct step in advance to this philosopher. Whereas the Pythagoreans had conjectured the presence of a central fire in the universe, Empedocles taught that the earth's center was composed of molten material. Empedocles formed this opinion on the basis of his actual observation of the volcanic activities of Mount Etna. Tradition says that he met his death by falling into the crater of that volcano.

Plato (427 B.C.), in his Cosmology, is a follower partly of Heraclitus and partly of Anaxagoras. According to Plato, the universe is the production of divine intelligence and of the necessary development of nature. The form of the whole universe is spherical; in the center lies the earth as a motionless sphere. An interesting account is given in the "Timæus" of a submerged Atlantic continent (Atlantis) on the other side of the Pillars of Hercules (Gibraltar). The idea of such a submerged continent has again and again received credence. In Plato's account Atlantis was larger than Asia and Libya together. It had been inhabited 9,000 years before his time, and since its destruction by earthquakes and inundations, navigation in the Atlantic had been impossible owing to the fine mud and detritus left by the vanished land. Another of Plato's theories related to the origin of rivers. He attributed them all to a common underground source.

The work of Aristotle (384-322 B. C.) marks the culminating point reached by the Greeks, both in the domain of speculative philosophy and in that of empirical observation. His treatises furnish an admirable exposition of the state of natural knowledge in his time. When he wrote, the geocentric view of the universe was still publicly accepted without question. But he had firmly grasped certain truths regarding the globe, which, tho taught long before by some of his predecessors, were not yet generally admitted. Accepting the common belief that the world consisted of four elements, he looked on these as arranged according to their relative densities. He said:

> "The water is spread as an envelope round the earth; in the same way above the water lies the sphere of air, while outside of all comes the sphere of fire."

With regard to the surface of the planet, Aristotle had formed some sagacious conclusions, tho mingled with certain of the misconceptions that were prevalent in his time. He remarks that earthquakes are due to a commingling of moist and dry within the earth.

> "Of itself, the earth is dry, but from rain it acquires much internal humidity. Hence when it is warmed by the sun and by the internal heat, wind is produced both within and without its mass. Wind, being the lightest and most rapidly moving body, is the cause of motion in other bodies; and fire, united with wind, becomes flame which is endowed with great rapidity of motion. It is neither water nor earth which causes an earthquake; it is the wind when what is vaporized outside returns into the interior."

Aristotle regarded earthquakes and volcanic eruptions as closely related phenomena. He states that it had been observed in some places that an earthquake has continued until the wind from the interior has rushed out with violence to the surface, as had then recently happened at Heracleia on the Euxine, and before that event at Hiera (Volcano), one of the Lipari Isles. At this latter locality the ground rose up with a great noise and formed a hill that broke up and allowed much wind to escape from the fissures, together with sparks and cinders which buried the whole of the neighboring town of the Liparans. The shock was even felt in some of the towns on the opposite mainland of Italy.

Aristotle was further led to propose an explanation of the great heat that forms part of the volcanic phenomena.

> "The fire within the earth can only be due to the air becoming inflamed by the shock, when it is violently separated into the minutest fragments. What takes place in the Lipari Isles affords an additional proof that the winds circulate underneath the earth."

This idea that volcanic action was mainly due to the movement of wind imprisoned within the earth obtained wide credence in antiquity. Æolus, the god of the winds, was believed to have his abode under the so-called Æolian Isles, which are all of volcanic origin and among which eruptions have been taking place since before the dawn of history.

This tireless observer of antiquity also discusses the phenomena presented by rivers and shows considerable acquaintance with the drainage system on the north side of the Mediterranean basin. He criticizes previously expressed opinions as to the source of rivers, particularly ridiculing the suggestion of Plato that all rivers flow directly from a vast mass of water under the earth. He appears to have held the opinion that just as the vaporized moisture in the atmosphere is condensed by cold and falls in drops of rain, so the moisture beneath the earth is similarly condensed and forms the sources of rivers.

He states that the mountains, by their cold temperature, condense the atmospheric moisture and receive a vast quantity of water, so that they may be compared to an enormous suspended sponge. He shows by geographical illustrations, drawn from Asia and the Mediterranean basin, that the largest rivers descend from the loftiest ground, where the water accumulates in numberless channels. He admits the possible existence of underground lakes from which rivers may issue and alludes to the disappearance of some streams into subterranean channels.

No writer of antiquity has expressed himself more philosophically than Aristotle regarding the past vicissitudes of the earth's surface. Having studied so carefully the operations of the various agents that are now modifying that surface, he recognized how greatly the aspect of the land must have been transformed in the course of ages. His remarks on this subject have a strikingly modern tone. He contemplates the alternations of land and sea and furnishes illustrations of them, much as a geologist of to-day might do.

> "The sea now covers tracts that were formerly dry land, and land will one day reappear where we now find sea.
>
> "These phenomena escape our notice because they take place successively during periods of time, which, in comparison of our brief existence, are immensely protracted. Whole nations may disappear without any recollection being preserved of the great terrestrial changes which they have witnessed from beginning to end."

The deluge of Deucalion, Aristotle suggests, affected Greece only, and principally the part called Hellas, and it arose from great inundations of rivers during a rainy winter. But such extraordinary winters, tho after a certain period they return, do not always revisit the same places. He concludes with these remarkable words:

> "It is clear that, as time never stops and the universe is eternal, the Tanais and the Nile, like all other rivers, have not always flowed; the ground which they now water was once dry. But if rivers are born and perish, and if the same parts of the land are not always covered with water, the sea must undergo similar

> changes, abandoning some places and returning to others, so that the same regions do not remain always sea or always land, but all change their condition in the course of time."

The great advances along certain lines of thought under the impetus of the Roman leadership infused a more realistic spirit into the investigations of all great workers in Natural Science, especially those interested in Geology. Among the latter the first place must be given to the historian and traveler Strabo (circa 63 B.C.), whose Geography, comprising seventeen volumes, was written about the beginning of the reign of Tiberius. It contains not a few important facts in regard to the general effects of subterranean energy.

Thus he cites a number of earthquakes by which chasms in the ground were formed, thousands of people were destroyed and cities were swallowed up. He also gives some information regarding volcanic eruptions which had taken place within the historical period in the Mediterranean region. In his time Mount Vesuvius was not only quiescent, but was not known ever to have been active. His quick eye, however, detected the true origin of the mountain. From the aspect of its summit he inferred that it was once a volcano, with live craters which had become extinct on the failure of the subterranean fuel, and he compared its slopes to the ground around Catania, where the ashes thrown out by Etna have formed an excellent soil for vines. He recognized the truly volcanic nature of the whole district from Etna to the Phlegraean Fields, under which Typhon, as Pindar sang, lay crushed on his burning bed. In his excellent account of the ascent of Etna, Strabo compares the molten lava to a kind of black mud which, liquefied in the craters, is ejected from them and flows down the sides of the mountain, cooling and congealing in its descent, until it becomes a motionless dark rock like millstone. He also attributes earthquakes to the force of winds pent up within the earth. The doctrine that volcanoes are safety valves, therefore, which has been quoted as a modern idea, is prior in origin to the beginning of the present era.

The oceanic islands far from any mainland have, according to Strabo, been thrown up by subterranean fires. In support of this view Strabo cited the case of a volcanic eruption in the year 196 B.C. between Thera and Therasia. For four days flames rose from the ocean, and as these died down it was observed that a new island had been formed, measuring twelve stadia in circumference. Strabo is therefore rightly regarded as the father of modern theories of mountain-making. He pointed out that Sicily in his time was less frequently disturbed by earthquakes than it had been in previous ages before volcanic discharges were known in the district, and he correlated the comparative tranquillity of the ground with the means of escape afforded for explosive underground vapors by the volcanic vents that had opened at Etna, in the Lipari Isles, and in Ischia. It speaks highly for Strabo's powers of observation that he should have recognized in Vesuvius a volcanic mountain, altho it was then quiescent.

Probably the most acute scientific observer of Roman times was Seneca, the physician of the Emperor Nero (2 B.C.-65 A.D.). Quite recently Nehring has placed the importance of the work of Seneca in its true light. The "Quæstiones Naturales" contain detailed communications about earthquakes, volcanoes and the constructive and destructive agencies of water. Seneca explains earthquakes partly as a result of the expansion of gases accumulated in the earth, partly by the collapse of subterranean cavities. He appears to have been much impressed by the earthquake which did so much damage in Campania on February 5th, 63 A.D., for he refers to it again and again, and furnishes from the lips of eye-witnesses some interesting particulars regarding it. Thus he tells how a flock of 600 sheep were killed in the district of Pompeii, a fate which he attributes to the rise of pestilential vapors from the ground. He was informed by a most learned and serious friend that when he was in the bath the tiles on the floor were separated from each other and were then driven together again, while the water at one moment sank through the opened joints of the pavement and thereafter boiled up again and was jerked out. The philosopher's account is the earliest detailed description of an earthquake which has come down to us.

Seneca regarded volcanic eruptions simply as an intensified form of the same series of phenomena and volcanoes themselves as canals or vents between local sub-terrestrial reservoirs of molten material and the earth's surface. In speaking of two outbreaks at Santorin, he remarks that an island rose out of the sea by protracted eruptions from below, and he notes that the internal fire is neither extinguished by the weight of the superincumbent depth of sea nor prevented from rushing to a height of a couple of hundred paces above the water. He speaks of Ætna having sometimes abounded in much fire and thrown out a great deal of burning sand, day being turned into night, to the terror of the population. On such occasions thunder and lightning are said to have abounded, but these came from the concourse of dry materials and not from ordinary clouds, of which probably there were none in such a raging heat of air—a shrewd anticipation of the modern distinction between ordinary atmospheric electric discharges and those evoked during the ejection of vapors, gases, dust and stones from a volcanic orifice.

The earth to him, however, was primitively a watery chaos, and it is more especially in his treatment of the action of water in dissolving and carrying away rock-materials, together with his explanation of the origin of sediments and deltas, that Seneca has shown his remarkable insight and sound judgment. His ideas on the origin of river water were no further advanced than those of his predecessors. He agreed with them in attributing all rivers to an inexhaustible internal source. Water being one of the four elements forms a fourth part of nature. Why then, he argued, should there be surprise if it can always keep pouring out? Just as in the human body there are veins which when ruptured send forth blood, so, he thought, in the earth there are veins of water which are found even in the driest places, at depths of two or three hundred feet, and which when laid open issue in springs and rivers. The water at these depths, so far below the limits to which rain can moisten the earth, is not regarded by him as of atmospheric origin, but living water (*aqua viva*).

The learned historian, Pliny the elder (23-79 A.D.), has handed down to us a compendium that embraces the whole scientific knowledge of antiquity. By a tragic decree of fate this untiring student and naturalist met his death while engaged in observing the grandest geological event of historic antiquity—the first outbreak of Vesuvius in the year 79 A.D. He died in the open field, probably suffocated by the volcanic vapor and ash. His corpse was found unharmed three days later, when the darkened sky finally became clear. The younger Pliny's vivid description of the eruption of Mount Vesuvius and the accompanying earthquake is one of the most remarkable literary productions in the domain of Geology.

CHAPTER II

THE BEGINNINGS OF MAP-MAKING

In the ancient records there is considerable doubt as to who were the earliest voyagers. Some authorities uphold the claim of the Greeks, some the Phenicians, others the Egyptians and still others the Chinese. Advocates of the Chinese claim base their conclusion on the location of the Ark of Noah. It is alleged that the ark rested on one of the mountains of Armenia and that Scythia was the first land to be inhabited, it being of high altitude and therefore the first to appear after the flood. But such an argument, based upon a local tradition, not upon scientific evidence, has little force.

Mankind—at least that portion whose history is familiar—dwelt upon the borders of an inland, mediterranean sea. They had never heard of such an expanse of water as the Atlantic and certainly had never seen it. The land-locked sheet which lay spread out at their feet was at all times full of mystery and often even of dread and secret misgiving. Those who ventured forth upon its bosom came home and told marvelous tales of the sights they had seen and the perils they had endured. Homer's heroes returned to Ithaca with the music of the sirens in their ears and the cruelties of the giants upon their lips. The Argonauts saw whirling rocks implanted in the sea, to warn and repel the approaching navigators, and as if the mystery of the waters had tinged with fable even the dry land beyond it, they filled the Caucasus with wild stories of enchantresses, of bulls that breathed fire and of a race of men that sprang, like a ripened harvest, from the prolific soil. If the ancients were ignorant of the shape of the earth, it was for the very reason that they were ignorant of the ocean. Their geographers and philosophers, whose observations were confined to fragments of Europe, Asia and Africa, alternately made the world a cylinder, a flat surface begirt by water, a drum, a boat, a disk. The legends that sprang from these confused and contradictory notions made the land a scene of marvels and the water an abode of terrors.

It is now generally conceded that the date of the maritime enterprises which rendered the Phenicians famous in antiquity must be fixed between the years 1700 and 1100 B.C. The renowned city of Sidon was the center from which their expeditions were sent forth.

About 1250 B.C. their ships ventured cautiously beyond the Straits of Gibraltar and founded Cadiz upon a coast washed by the Atlantic. A little later they founded establishments upon the western coast of Africa. Homer asserts that at the Trojan War, 1194 B.C., the Phenicians furnished the belligerents with many articles of luxury and convenience, and their ships brought gold to Solomon from Ophir in 1000 B.C.

About the period of Tyre's greatness (600 B.C.) the Phenicians, tho under Egyptian commanders, appear to have succeeded in the circumnavigation of Africa. The enterprise was undertaken by order of Necho, king of Egypt, and is commented on by Herodotus as follows: "Having in this manner consumed two years, in the third they passed the Pillars of Hercules and returned to Egypt. This story may be believed by others, but to me it appears incredible, for they affirm that when they sailed round Libya they had the sun on their right hand."

In the time of Herodotus the Greeks were unacquainted with the phenomenon of a shadow falling to the south, one which the Phenicians would naturally have witnessed had they actually passed the Cape of Good Hope, for the sun would have been on their right hand, or in the north, and would thus have projected shadows to the south. "As this story was not one likely to have been invented in the time of Necho," suggests F. B. Goodrich in his "Man Upon the Sea," from which some of these adventures are condensed, "it is the strongest proof that could be adduced of the reality of the voyage.

"The first maritime adventure among the Greeks which lays any claim to authenticity, and the most celebrated in ancient times, is the expedition of the Argonauts to Colchis. The date of the expedition, if it took place at all, may be safely fixed at the year 1250 B.C. A theory propounded by Sir Isaac Newton would connect it with the year 937, but this is regarded with less favor than the earlier date. Its alleged object was the Golden Fleece, but what this was can only be conjectured."

Jason, the son of the King of Thessaly, being deprived of his inheritance and having resolved to seek his fortune by some remote and hazardous expedition, was induced to go in quest of the Golden Fleece in Colchis. He enlisted fifty men and employed Argus to build him a ship, which from him was called Argo, the adventurers being named Argonauts.

The Argonauts started their voyage from Iolcos in Thessaly, and with a south wind sailed east by north. The narrative of the expedition is full of wonders. They landed at the Island of Lemnos, where they found that the women had just murdered their husbands and fathers.

The Argonauts supplied the place of the assassinated relatives, and

Jason had two sons by one of the bereaved Lemnians. When the vessel arrived at the entrance to the Euxine—the narrow strait now called the Bosphorus—they built a temple and implored the protection of the gods against the Symplegades, or Whirling Rocks, which guarded the passage. A seer named Phineas was consulted upon the probability of their sailing through unharmed. The rocks were imagined to float upon the waves, and, when anything attempted to pass through, to seize and crush it.

Phineas advised the loosing of a dove and to judge from its fate of the destiny reserved for them. They did so, determined to push boldly on if the bird got through in safety. The pigeon escaped with the loss of some of its tail-feathers. The Argo dashed onward and cleared the formidable rocks with the loss of a few of its stern ornaments. From this time forward, the legend adds, the Symplegades remained fixed and were no longer a terror to navigators. The Argonauts, after entering the Black Sea, sailed due east to the mouth of the River Phasis, now the Rione. Ætes, the king, promised to give Jason the fleece upon certain conditions. These he was enabled to fulfil by the aid of Medea, a sorceress and daughter of Ætes. They then fled together to Greece. This route followed by the Argonauts upon their return is differently given by the various poets who have told the story and the commentators who have illustrated it.

The Greeks, like the Hebrews, were ignorant of the real figure of the earth. It is in Homer that is found the first written trace of the widely prevalent idea that the earth is a flat surface begirt on every side by the ocean. This was a natural belief in a region almost insular, like Greece, where the visible horizon and an enveloping sea suggested the idea of a flat circle. Homer took the lead among the poetic geographers of Greece, and his authority gave to the subject a fanciful cast, the traces of which are not yet obliterated. Beneath the earth he placed the fabled regions of Elysium and Tartarus; above the whole rose the grand arch of the heavens, which were supposed to rest on the summits of the highest mountains. The sun, moon and stars were believed to rise from the waves of the sea and to sink again beneath them on their return from the skies.

Homer's distribution of the land was even more fantastic. Beyond the limits of Greece and the western coasts of Asia Minor his knowledge was uncertain and obscure. He had heard vaguely of Thebes, the mighty capital of Egypt, and in his verse sang of its hundred gates and of the countless hosts it sent forth to battle. The Ethiopians, who lived beyond, were deemed to be the most remote dwellers upon the habitable earth. Toward the center of Africa were the stupendous ridges of the Atlas Mountains. Homer defined the highest peak and made it a giant supporting upon his shoulders the outspreading canopy of the heavens.

The narrow passage leading from the Mediterranean to the Atlantic, and now known as the Straits of Gibraltar, was believed to have been discovered by Hercules, and the mountains on either side—Gibraltar and Ceuta—were, from him, called the Pillars of Hercules. Colchos, upon the Black Sea, was believed to be an ocean city, and here Greek fancy located the Palace of the Sea. It was here that the charioteer of the skies gave rest to his coursers during the night and from whence in the morning he drove them forth again. Colchos, therefore, was Homer's eastern confine of the globe.

On the north Rhodope, or the Riphean Mountains, were supposed to enclose the hyperborean limits of the world. Beyond them dwelt a fabled race, seated in the recesses of their valleys and sheltered from the contests of the elements. They were represented as exempt from all ills, physical and moral, from sickness, the changes of the seasons and even from death. A race directly the converse of the ideal hyperboreans were the Cimmerians, located at the south of the Sea of Azof, who are described by Homer as dwelling in perpetual darkness and never visited by the sun. He imagines the existence of numerous other nations, who long continued to hold a place in ancient geography. The Cyclops, who had but one eye, were placed in Sicily; the Arimaspians, similarly afflicted, inhabited the frontiers of India; the pigmies, or dwarfs, who fought pitched battles with the cranes, were supposed to dwell in Africa, in India, and, in fact, to occupy the whole southern border of the earth.

"In the time of Homer," says F. B. Goodrich, "all voyages in which the mariner lost sight of land were considered as fraught with the extremest peril. No navigator ever visited Africa or Sicily from choice, but only when driven there by tempest and typhoon, and then his woes usually terminated in shipwreck; a return was not merely a marvel but a miracle. Homer made Sicily the principal scene of the lamentable adventures of Ulysses, and sufficient traces are furnished by the Odyssey of the distorted and exaggerated notions entertained in the poet's time of the character of places reached by a voyage at sea. The existence of monsters of frightful form and size, such as Polyphemus; of treacherous enchantresses, such as Circe; of amiable goddesses, like Calypso, were prefigured by the early geographers and the location of their homes marked on the early charts. The radius of the territories described by Homer with any degree of precision was hardly three miles in length."

Hesiod, who lived a century after Homer, thus states the scientific attainments of his time: "The space between the heavens and the earth is exactly the same as that between the earth and Tartarus beneath it. A brazen anvil, if tossed from heaven, would fall during nine days and nine nights and would reach the earth upon the tenth day. Were it to continue its course toward the abode of darkness it would be nine days and nine nights more in accomplishing the distance."

Anaximander, four hundred years after Homer, held that the earth instead of being flat, was in the form of a cylinder, convex upon its upper surface. Its diameter was three times greater than its height and its form was round, as if it had been shaped by a turner's lathe. The Oracle of Delphi was the center of his system.

At a period which it is no longer possible to settle with precision, but certainly anterior to the fifth century B.C., the Carthaginians, then in the height of their maritime and commercial prosperity, ordered a navigator by the name of Hanno to make a voyage beyond the Pillars of Hercules and to found cities along the western shore of Africa. He set sail with a fleet of sixty vessels, each of which was impelled by fifty oars. He carried with him thirty thousand men and women, with abundant supplies and provisions.

The narrative, as given by Hanno himself, hardly fills two octavo pages; volumes of commentaries have been written upon it by geographers and antiquaries. The most probable of the various hypotheses formed upon it is that Hanno's voyage extended to Sherbro Sound, a little south of Sierra Leone. The features of man and nature, as described by Hanno, are to be found in tropical Africa only.

While Hanno was thus exploring the western coast of Africa, another Carthaginian, named Himilcon, was sent by his countrymen to the north of Europe. From a very vague description of his voyage, given in a Latin poem entitled "Ora Maritima," it is plain that he crossed the Bay of Biscay and found upon islands, as is asserted, but probably upon the mainland, a race of athletic people who went fearlessly to sea in barks made of skins sewed together. They crossed, in the space of two days, to a place called the Sacred Island (Ireland), which was not far from another island, named Al-Bion (England). No further details of this expedition have been preserved.

A colony which had been established at Massilia—now Marseilles—about six hundred years before Christ by the Phocians was, in the year 340 B.C., at the height of its commercial prosperity. The citizens, being desirous of extending their maritime relations, sent at this period upon an expedition to the north of Europe, through the Pillars of Hercules, a learned geographer and astronomer by the name of Pytheas. He started with a single ship. He passed the Pillars on the sixteenth day from Massilia, and on the twentieth he arrived at the Sacred Promontory, the extreme western point of Iberia or Spain. A temple to Hercules had been erected at this spot. The inhabitants of the promontory declared during the time of Pytheas and indeed for two hundred years afterward that as the sun plunged at evening into the sea they heard a hissing like that of a red-hot body suddenly dropped into water. Following the coasts of Iberia and of Celtica, he came to the point of land now known as Finisterre, in France, and the promontory Calbium.

Turning to the east, he was surprised to find himself in a wide gulf, with Celtica on his right and an immense island on his left. The gulf was the British Channel and the island the Al-Bion that Himilcon had vaguely discerned some centuries before. It was at this point that Pytheas may be said to have begun his career, and the discovery of Great Britain may safely be attributed to him. He described the island as having the form of an isosceles triangle. Three promontories formed the three angles: Belerium being now Land's End; Cantinum, Cape Pepperness; and Orcas, Duncansby Head. He found the inhabitants of the southern coast industrious and sociable, peaceable, honest and sober. They raised wheat and worked rich mines of tin. As he sailed northward, along the eastern coast, he noticed that the days grew sensibly longer, and at Point Orcas nineteen hours elapsed between the rising and the setting of the sun. He sailed still northward, and six days after leaving Orcas he came to an island or a continent—he knew not which—which he called Thule.

As he found he could go no farther to the north, he spoke of this spot as Ultima Thule, an expression which has passed into the figurative language of all modern nations as one denoting any remote point. Thule is generally considered to have been Shetland, although theories have been ardently advocated making it respectively Iceland, Sweden and Jutland.

The narrative of Pytheas, which has been thus far clear and reliable, assumes at this point a fabulous aspect. He declares that north of Thule there was neither earth, nor sea, nor air. A sort of dense concretion of all the elements occupied space and enveloped the world. He compared it to the thick, viscid animal substance called pulmo marinus, a sort of mollusk or medusa. He said that this substance was the basis of the universe, and that in it earth, air and sky hung, as it were, suspended.

This illusion has been explained by the dreary spectacles of fogs, mists, rains and tempests which at this point of his voyage must have met the gaze of the daring navigator. It would have been difficult for any mind in those early ages to have been on its guard against the sinister impressions likely to result from the contemplation of a scene so appalling. It must be remembered that Pytheas was accustomed to the pure and transparent atmosphere, the dazzling sky and the phosphorescent waters of the Mediterranean. It would have been astonishing if a man educated among the splendors of an almost tropical climate had not been oppressed by influences so gloomy.

In the year 863 a Dane of Swedish origin, named Gardar, adventurously pushing off into the Northern Ocean, discovered the island-rock whose appropriate name is Iceland. Eleven years later a navigator named Ingolf colonized the country, the colonists, many of whom belonged to the most esteemed families in the north, establishing a flourishing republic. In 877 a sailor named Gunnbjorn saw a mountainous coast far to the west, supposed to be now concealed or rendered inaccessible by the descent of Arctic ice.

Erik the Red, who had been banished from Norway for murder and had settled in Iceland, was in his turn outlawed thence in 983; he sailed to the west and discovered a land which he called Greenland, because, as he said, "people will be attracted hither if the land has a good name." He returned to Iceland, and in the year 985 a large number of ships—according to some authorities, thirty-five—followed him to the new settlement and established themselves on its southwestern shore.

In 986 Bjarni Herjulfson-Bjarni, the son of Herjulf, in a voyage from Iceland to Greenland, was driven a long distance from the accustomed track. Various data furnished by this narrative, in the original Iceland records, have enabled geographers to determine the various coasts dimly seen by Bjarni, but upon which he did not land. They are supposed to have been those of Long Island, Rhode Island, Massachusetts, Nova Scotia and Newfoundland.

In the year 994 Leif Erikson—Leif the son of Erik the outlaw—bought Bjarni's ship and engaged thirty-five men to navigate it, as he intended to sail upon a voyage of discovery. He asked his father, Erik, to be the captain; but Erik declined, being, as he said, well stricken in years. They sailed away into the sea and discovered first the land which Bjarni had discovered last. They went ashore, saw no grass, but plenty of icebergs and an abundance of flat stones. From the latter circumstance they named the place Helluland, hellu signifying a flat stone. There can be no doubt that the spot thus named is the modern Newfoundland. They went on board again and proceeded on their way. They went ashore a second time where the land was flat and covered with wood and white sand. "This," said Leif, "shall be named after its qualities and called Markland" (woodland). Again embarking and sailing to the south, they reached "Vinland," so called because of the wild grapes. This was probably the first recorded landing on the eastern shore of what is now the United States.

Thus beginning from a fearful restraint of venturing upon the sea, the ancients first explored the Mediterranean, then, growing bolder, ventured beyond the Straits of Gibraltar and crept along the

African coast and up toward the north of Europe. The perils of the open ocean were first dared by the Norsemen, to whom is due the honor of having first landed upon and truly discovered the continent of America, an honor furthered by Columbus, Amerigo Vespucci and later navigators.

The next great event was the doubling of the Cape of Good Hope by Bartholomew Diaz in 1486. He had indeed doubled it without knowing it, for having taken a wide sweep to sea after a long southern voyage, on again making for the land he could find none; only on turning to a more northerly course did he see land one hundred miles to the eastward of the formidable cape which never before had been passed.

It avails little to tell the voyage of Columbus and his discovery of the West Indies in 1492 or of the curious circumstances which led to the use of Amerigo's name. The Florentines were eager to have Amerigo's work recognized, and when a Frenchman of St. Dié republished his narrative, making an error in the date which made it seem that Amerigo preceded Columbus, Florence took it up and Spain made no protest in favor of Columbus, whom she had allowed to die in penury and disgrace. Sebastian Cabot, a true navigator, discovered Hudson's Bay in 1518.

Vasco de Gama in 1497 followed the track of Bartholomew Diaz and reached India by doubling the Cape of Good Hope. It did not occur to him, however, to continue his journey, and in returning to Portugal he retraced his path. In 1519 Ferdinand Magellan found the straits between the Atlantic and the Pacific which are known as the Magellan Straits to this day, and one of the vessels of his expedition was the first to circle the earth.

With the circumnavigation of the globe and the opening of all oceans to daring navigators, nautical exploration practically ceased. Since that time numberless geodetic surveys have been made. These form the modern counterpart of the quests of the sailors of olden time. Instead of vaguely determining the positions of continents the modern maritime surveyor determines the precise positions of minor points on the shores of mainlands or islands, and charts the submerged reefs.

With the Challenger expedition sent out by the British government in 1872, a new kind of exploration was born. This was the exploring of the ocean bed, the discovery of mountains and valleys, "shallows" and "deeps," beneath the ocean's surface. For, be it remembered, the bed of the ocean is almost as much carved as is the surface of the land. From the depth of the lowest deep to sea level is a greater mountain elevation than from the sea level to the summit of Mt. Everest.

This form of exploration has gone on continuously, each succeeding decade adding to the knowledge of the sea bottom, and in this work the American navy has taken a leading place. The greatest ocean depth yet charted was found in 1912 off the north coast of Mindanao, Philippine Islands, a depth of 32,078 feet being recorded. This is 2,907 feet greater than the height of the highest peak of the Himalayas.

One of the most important submarine explorations of recent years was reported in 1913, when Sir Douglas Mawson produced evidence of the remains of a continent stretching from Tasmania to Antarctica. Although the shallowest water over this submerged continent is 545 fathoms, or over 3,270 feet, the ridge—which is 150 miles long—rises at least 11,000 feet above the ocean floor. This discovery has been of incalculable importance in explaining certain similarities of animal life in Tasmania, Australia, and South America.

Exploration in its more familiar meaning has recently been directed to Polar search, and the Twentieth Century will forever stand out memorable in the annals of human history, since both the North and South Poles have been reached. Not until one fully realizes for how many centuries indefatigable and heroic seekers have essayed this perilous adventure, not until one reckons the awful toll of life, does the sheer splendor of the work of Commander Peary, Captain Amundsen and Captain Scott stand out in its true colors.

In the reign of Henry VIII, Doctor Robert Thorne declared that "if he had facultie to his will, the first thing he would understande, even to attempt, would be if our seas northwards are navigeable to the Pole or no." Accordingly "two faire ships" set forth in May, 1527. One of these vessels was wrecked off Newfoundland and there is no record that the other ever returned. A similar fate met Sir Hugh Willoughby, who sailed in 1563. He lost one vessel on "the Muscovy coast" and, with all his companions, perished miserably in Lapland.

Martin Frobisher, the great navigator, was not able to reach further north than 63°, but in 1585 Captain John Davis reached lat. 80° and on his third voyage he reached even further, sighting land which he named Cape Sanderson, a few minutes north of the point attained on his former voyage. Henry Hudson, the explorer of the Hudson River, in an attempt to reach the Pacific Ocean by the long sought North West passage, in 1607 attained the latitude of 81°. The last of the early explorers was William Baffin, who in 1615 sailed around Greenland, giving his name to Baffin's Bay.

The nineteenth century was remarkable for strenuous endeavor. In 1818 Sir John Parry overtopped all earlier efforts and reached as far north as 82°. The hopes of the world, however, rose high when, in the spring of 1845, Sir John Franklin sailed for polar waters. The silence of the Arctic winter fell over the expedition, and rescue parties later found the bodies of Franklin and his men, who had died in forwarding their quest. Scarcely less tragic was the loss of the American De Long expedition in 1881.

The great figure in Polar work during the nineteenth century unquestionably was Commander Robt. E. Peary, who in 1886 first attacked the Arctic terrors. His first expedition was to Greenland, and from that time he has been almost constantly in the Arctic region under the auspices of several learned and scientific societies. But in spite of his indefatigable efforts, a Norwegian, Dr. Nansen, carried off the banner for the highest point reached in the nineteenth century. He built a vessel—the *Fram*—to withstand ice pressure and trusted that the currents would carry him to the Pole. He reached latitude 86° 14′, and brought back a mass of extremely useful scientific information.

An attempt to reach the North Pole by balloon was made by Prof. Andre in 1897. The expedition was never heard from, for aero-navigation had not then made the wonderful advances compassed in the first two decades of the twentieth century.

The last year of the century saw the northern mark again pushed forward. An expedition under the command of the Duke of the Abruzzi sailed in 1899. Dr. Nansen's furthest point was passed, and a dash was being made for the Pole when the leader of the expedition was severely frostbitten, and he accordingly transferred the perilous command to Capt. Cagni, who reached the point of latitude 86° 34′.

Two succeeding important Arctic expeditions may be mentioned: the Ziegler expedition commanded by Anthony Fiala in 1903 and that of Capt. Amundsen. Fiala spent two years above the 81st parallel, and added greatly to polar knowledge; and Amundsen achieved the North West passage—which had baffled the world for centuries—in his tiny ship the *Gjoa.*

It was on April 6, 1909, that Commander Robert E. Peary, U.S.N., brought himself imperishable fame by the conquest for the North Pole. The triumph was accentuated by the fact that (except for the last dash for the Pole) Commander Peary was accompanied by a scientific staff of considerable eminence and that the results of his exploration were as profitable in scientific value as they were thrilling in their daring.

Leaving Etah on August 17, 1908, the *Roosevelt* reached Cape Sheridan, on the shore of the Arctic Sea, on September 1. There Peary established a winter camp. Throughout the winter, sledging parties carried loads of provisions to a northern camp at Cape Columbia, and on February 15, 1909, the first of the five detachments of the North Pole sledge party left Cape Sheridan. The distance from Cape Columbia—the last mainland point—was 575 miles.

As Peary advanced, one after another of the supporting parties were returned to their base, and, when the North Pole was but 140 miles distant, preparations were made for the final dash. Only five men participated in the final burst of speed, Commander Peary, Matt

Henson (his colored servant) and three Eskimos. The distance was covered in five forced marches of forty hours, and the Pole was reached before noon on April 6, 1909. Thirty hours were spent in taking observations under a cloudless sky and with a temperature not exceedingly cold. The lowest temperature recorded during this time was —30° Fahr. The ice at the Pole was described as "chalky white" and practically level.

At the North Pole there is no land. The soundings made by Commander Peary, five miles from the Pole, gave a depth of 1,500 fathoms without touching bottom. As Nansen discovered a deep oceanic basin in Asian Arctic waters, the existence of an Arctic continent of any considerable size is disproved.

Shortly before the news arrived of Commander Peary's success, Dr. Frederick A. Cook made the claim of having attained the North Pole on April 21, 1908. Until competent evidence disproved his assertions, Dr. Cook secured wide publicity and some notoriety. Official investigation showed that the Eskimos who were supposed to have accompanied Dr. Cook to the Pole had wintered with him in Jones Sound, and they asserted that he had not gone north at all. His supposed observations of latitudes and longitudes, it was shown, had been forged for him by a mathematician in Europe. The supposed scientific data he sent to the University of Copenhagen were declared by that body to be self-contradictory. His name was publicly stricken from the records of many organizations which had yielded credence to his first unexamined report.

Further interest in the Arctic has been divided between the Stefansson and Crocker Land expeditions, both for the purpose of determining the geographical boundaries of unmapped portions of land in the Arctic Ocean. Stefansson's work as an ethnologist has resulted in the acquisition of a vast body of knowledge concerning the natives of regions never before visited by white man. In November, 1915, Stefansson sailed again for the North with a well equipped scientific corps. He took provisions for two or even three years and a hundred and sixty dogs.

In scientific observations the Crocker Land expedition has been fruitful. It sailed on July 2, 1913, from Brooklyn on the steam whaler *Diana* for Smith Sound. It was in charge of Donald B. MacMillan, an ethnologist of note, with a staff of scientists on board to help him with the observations. It was planned that the expedition establish winter quarters on Ellesmere Island and start eastward for the supposed Crocker Land in February, 1914. Peary gave this name to land which he saw in the west during his survey of Grant Land in 1906. It was the purpose of MacMillan to find if this land existed and then to explore it.

In 1914, after a long journey, MacMillan reported that the Crocker

Land had disappeared from the charts of the Polar Ocean, due to geographical inaccuracies, frequent in polar exploration. MacMillan and Ensign Green in March, 1914, started on a perilous journey across the floes of the Arctic Ocean, in a quest for the land, but although they reached a point in the neighborhood of 82° 30′ N. latitude, 102° W. longitude, where Peary had charted the land, it was not seen. Most of the dogs were lost, and the two explorers reached land only barely in time to save their own lives, for the next day the polar pack was entirely disrupted. Their soundings and collections promise to be of great interest, and the biological and geological material gathered by the party is most valuable.

The history of Antarctic exploration begins in 1768, when Captain James Cook, the great English navigator of the eighteenth century, discovered that New Zealand was an island. In 1773, Captain Cook sailed to the south again and reached latitude 71°. The next great name in South Polar exploration was Sir James Ross, who discovered the active volcano of Mt. Erebus and its twin peak Mt. Terror in latitude 77°. The next southing was reached by Captain Borchgrevink in 1889, who attained latitude 78°, and the following year located the South Magnetic Pole in latitude 73°. In 1903, Captain Scott reached latitude 82°.

One of the finest sledging exploits on record was that of Lieutenant Shackleton, who, on January 9, 1909, reached within 111 miles of the South Pole, but was compelled to return because of the impassable character of the lofty land masses and by insufficiency of rations. While Lieutenant (afterwards Sir Ernest) Shackleton did not discover the South Pole, the honor of having discovered the continent of Antarctica undoubtedly should be assigned to him.

On December 16, 1911, Captain Roald Amundsen reached the South Pole. Disregarding Sir Ernest Shackleton's experience with Manchurian ponies, Amundsen depended entirely upon skiis and Eskimo dogs. He wintered as far south as 81°, and spent a large part of the winter ensuring against any members of the expedition becoming lost. On October 20, the southern march was begun, the party numbering only five men. The conditions of travel at first were severe, as the road he took to the South Pole was over the peaks of South Victoria Land. Once the lofty plateau was attained, however, travel was easy, and Amundsen remained satisfied with short marches, the average advance daily being only about 17 miles.

At the South Pole Amundsen remained 24 hours and took a complete series of observations. A small tent which the explorer had brought with him was erected at the Pole, and the Norwegian flag was left flying above it.

Saddest among all the splendid exploits with which Polar research has been adorned was the achievement of the South Pole by Captain

R. F. Scott, thirty-five days after Amundsen's discovery, and the British explorer's death on his return to his base of supplies. He was within eleven miles of safety when a blizzard overtook the party, and a camp was made in the snow. There was then enough fuel for one hot meal and food enough for four meals. But the blizzard showed no signs of cessation. Captain Oates, one of the members of the party, feeling that there was a greater chance for Captain Scott's return if there were fewer mouths to feed, deliberately walked out into the blizzard and perished. The sacrifice was in vain, for six months afterwards a rescue party found the bodies of Captain Scott and his companions, together with a complete diary giving a detailed account of his trip, of his discovery of the Pole and the records; and until his fingers began to stiffen in death, every incident of the fatal return journey was faithfully and touchingly set down.

While land exploration now deals mainly with the topography of little known regions and is carried on by the governments of the world, it is not without its dangers. Mr. Noel Williamson, in 1910, while engaged in mapping the Assam-Thibet borderland, was massacred with two hundred of his natives. Dr. Sven Hedin, however, has succeeded in exploring the whole of Western Thibet and has certified the modern knowledge of Central Asia. It was in 1908 that he completed this exploration, during which he made a complete survey of the main topographical features of the whole of western Tibet. He discovered a part of the Trans-Himalaya Range and the main upper branch of the Indus River. It took three years to complete the work, and it is therefore possible now to construct a map of that hitherto unknown region.

The most important exploratory work, now being done year by year, is the work of boundary commissions. Thus the demarcation of the Alaskan-Canadian boundary from Mt. St. Elias northward to the Arctic Ocean along the 141st meridian of west longitude, was completed in 1915. The regions were of extreme ruggedness and were deemed almost inaccessible. In the Nigeria-Kamerun boundary commission's work, three new pigmy tribes were found. An effort to explore the unknown desert of Arabia was prevented by hostile tribes, though Captain Leachman was successful in making his way from Damascus to Ojair on the Persian Gulf through Central Arabia. Another new group of dwarfs was found in 1914 by an expedition under Kingdon Ward on the Chungtien plateau. Dr. and Mrs. Workman have disclosed vast unknown portions of the Himalayas and in 1913 discovered the Siachen glacier system, the largest in the world.

Dr. M. A. Stein added to the study of Central Asia by mapping 17,000 square miles of mountain land in the Chinese province of Kansu and along the eastern border of East Turkestan. He found many ruins of ancient towns, and it took fifty camels to transfer his vast collections of historic relics.

British and French expeditions have mapped the dark continent of Africa, and even the deserts of Central Australia have been crossed by many surveys. Colonel Theodore Roosevelt's hunting expedition, which returned in 1910, added greatly to the knowledge of fauna and flora of Africa. About 11,000 specimens were brought to the United States National Museum. In South America also the most notable expedition was made by a party headed by Colonel Theodore Roosevelt, resulting in the navigation of a river—now called by the Brazilian government Rio Teodoro—a large section of which had never been visited. It proved to be a tributary of the Madeira, which in its turn is a southern tributary of the Amazon. Although very tortuous, the general course of the Rio Teodoro is due north, through a rugged, densely wooded country, uninhabited by man and almost devoid of beast. The voyage involved a journey of 750 kilometres and lasted two months, from February to April, 1914. The scarcity of game, limited food and fever conditions added to the difficulties of the undertaking. Thirty unnavigable rapids made the voyage both exhausting and dangerous.

Since the conquest of the poles has been achieved, since the interiors of the great continents have been forced to yield up their secrets, since the abysmal depths of the ocean are charted, exploration has taken to itself wings. In America, as in Europe, great activity is being manifested in the preparation of aeronautical maps, charts which reveal the direction of air currents as nautical charts reveal those of ocean currents. Dangerous vortices or air-whirls are to be marked upon these maps like reefs upon the ocean. These maps include an area of one degree each of latitude and longitude. Railways, rivers and canals are also shown by suitable colors and symbols. Objects of special form or prominence, such as heights, buildings and aerodromes are clearly indicated. With the advance in meteorological science and aviation mechanics, it is expected that flight through the air may be as safely protected as travel on the sea.

CHAPTER III

GEOLOGY IN THE DARK AGES

The decline of the Roman Empire, while, as has been seen, it did not prevent the growth of the adventurous spirit, was a sore blow to scientific study. Life became too insecure to permit leisure, and the governmental situation was uncertain in all countries.

From the middle of the eighth century onward for some five hundred years the Arabs alone kept alive the feeble flame of interest in researches into the secrets of Nature. With great labor and at large cost they procured as much as they could obtain of the literature of Ancient Greece and Rome and studied and translated into their own language the works of the best writers in philosophy, medicine, mathematics and astronomy. They were thus able to some extent to enlarge the domain of these subjects. But Geology was a subject to which the students of the Caliphates never took kindly.

Albert the Great (1205-1280 A.D.), the most learned man of his time, mentions that a branch of a tree was found on which was a bird's nest containing birds, the whole being solid stone. He accounted for this strange phenomenon by the "vis formativa" of Aristotle, an occult force, which, according to the prevalent notions of the time, was capable of forming most of the extraordinary objects discovered in the earth.

One of the keenest observers whose opinions have been recorded was the illustrious painter, architect, sculptor and engineer, Leonardo da Vinci (1452-1519). His attention having been aroused by the abundantly fossiliferous nature of some of the rocks in northern Italy, in which canals were cut, he concluded that the shells contained in these rocks had once been living creatures on the sea-floor and had been buried in the silt washed off the land. He ridiculed the notion that they could have been produced by the influence of the stars, and he asked where such an influence could be shown to be at work now. But he pointed out that besides the shells, there were at various heights terraces of gravel composed of materials that had evidently been rounded and accumulated by moving water.

Fracastoro, in the year 1517, gave clear expression to his convictions about fossils, which were in accordance with those of Leonardo da Vinci. During the building of the citadel of San Felice in

Verona, the workers found fossil mussels in the rocks and laid them before Fracastoro, begging him to explain the marvel. Fracastoro repudiated the doctrine of a "vis plastica" in the earth as impossible, and just as little did he give credence to the view that explained fossils as creatures left by the great Flood. There was left, he continued, only one possible explanation—that the fossils were the remains of animals which had once lived in the localities where their remains are now imbedded.

Far more illustrious than the majority of his contemporaries in science was George Bauer, better known by his "nom de plume" of Agricola. Werner calls him the father of metallurgy and the originator of the critical study of minerals. Agricola's observations on crystalline form, cleavage, hardness, weight, color, luster, etc., have served as a model for all subsequent descriptions of minerals. On the other hand, Agricola's remarks about fossils are of much less value. He had devoted little attention to the fossil remains of animals and plants, and he unfortunately united under the name "Fossilia" both minerals and petrified organisms. This use of the term "Fossils" was perpetuated for two centuries in the literature, having been more especially adopted by the famous Wernerian school.

Giulio Cardano (1552) pointed to fossil shells as certain evidence that the sea once covered the sites of the hills. The skilful anatomist, Gabriel Falloppio (d. 1562), when he met with the bones of elephants, teeth of sharks, shells and other fossils, refused to admit them to be anything but earthly concretions, because he deemed that to be a simpler solution of the problem than to suppose that the waters of the Deluge could have reached as far as Italy.

It is astonishing to find how tenaciously, until the middle of the eighteenth century, so many authors clung to most absurd ideas, even altho the fossils were being made known by means of good illustrations to an ever-increasing number of observers. The works of Aldrovandi, Athanasius, Kircher the Jesuit, Sebastian Kirchmaier, Alberti, Balbini, Geyer, Hartley and many others in the seventeenth century contain good figures and extended the knowledge of the fossils found in various European localities. The fossils were, however, treated usually as mineral curiosities or as illusions of nature, sometimes as forms called forth in the earth by "vis plastica" or some other force, sometimes compared with living mussels, snails, sea-urchins and plants, and named accordingly.

In the crowd of writers who took part in the long geological controversy by far the most illustrious was Nicolas Steno (1631-1687). Born and educated in Copenhagen, he traveled to Leyden, Paris and Austria and eventually settled in Florence as physician to the Grand Duke Ferdinand the Second.

In 1669 there appeared in Florence his treatise, "De Solido intra soliaum naturaliter contento," which must be regarded as one of the landmarks in the history of geological investigation. In this he says that the strata of the earth are such as would be laid down in the form of sediment from turbid water. The objects enclosed in them, which in every respect resembles plants and animals, were produced exactly in the same way as living plants and animals are produced now. Where any bed encloses either fragments of another and therefore older bed or the remains of plants or animals, it cannot be as old as the time of the Creation. If any marine production is found in any of these strata, it proves that at one time the sea has been present there, while if the remains are those of terrestrial plants or animals, the sediment must have been laid down on land by some river or torrent.

Another notable Italian writer, Anton-Lazarro Moro, appeared in the first half of the eighteenth century. He discussed the possibility of explaining the position of fossil shells in the mountains by reference to the Noachian Deluge and dismissed this supposition as untenable. After giving an account of the uprise of a new volcanic island in the Greek Archipelago in the year 1707, of the appearance of Monte Nuovo near Naples in 1538 and of the recorded eruptions of Vesuvius and Etna, and starting with the proposition that the fossil shells are really productions of the sea, he proceeds to unfold his theory that the position of these shells, and the origin of the rocks that enclose them, are to be assigned to the operation of volcanic action.

The following semi-tragic, semi-comic event was a decided setback to the prevailing belief in the theory of the direct origin of fossils—*i.e.*, that they were imitations produced in the rocks by some unknown causes: Johannes Bartholomew Beringer, a professor in the University of Wurzburg, published in 1726 a paleontological work entitled "Lithographia Wurceburgensis." In it a number of true fossils were illustrated, belonging to the Muschelkalk or Middle Trias of North Bavaria, and beside these were more or less remarkable forms, even sun, moon, stars and Hebraic letters, said to be fossils, and described and illustrated as such by the professor. As a matter of fact, his students, who no longer believed in the Greek myth of self-generation in the rocks, had placed artificially concocted forms in the earth, and during excursions had inveigled the credulous professor to those particular spots and discovered them! But when at last Beringer's own name was found apparently in fossil form in the rocks, the mystery was revealed to the unfortunate professor. He tried to buy up and destroy his published work, but in 1767 a new edition of the work was published, and the book is preserved as a scientific curiosity. Many of the false fossils (Lugensteine) may be seen in the mineral collections at Bamberg.

Palissy, a French writer on "The Origin of Springs from Rainwater" and of other scientific works, undertook in 1580 to combat the notions of many of his contemporaries in Italy that petrified shells had all been deposited by the Universal Deluge. "He was the first," said Fontenelle when, in the French Academy, he pronounced his eulogy, nearly a century and a half later, "who dared assert in Paris that fossil remains of testacea and fish had once belonged to marine animals." Palissy's ideas were violently attacked by his compatriots, and he was denounced as a heretic.

Next among the notable workers was the versatile B. F. Guettard, who traveled through France, England, Germany and Poland, and whose great desire it was to reproduce his scientific observations on maps. Guettard described the processes of land denudation effected by the solvent and destructive agency of rain and rivers and by the abrasion of the waves. This is probably the first paper in which a systematic account of denudation is given in its relation to changes in the configuration of the earth's surface. The most brilliant of Guettard's achievements was his discovery of the volcanic rocks in the Auvergne region.

Toward the close of the eighteenth century the idea of distinguishing the mineral masses on our globe into separate groups and studying their relations began to be generally diffused. Of these investigators, Pallas and de Saussure were among the most celebrated whose labors contributed to this end. After an attentive examination of the two great mountain chains of Siberia, Pallas announced the result that the granite rocks were in the middle, the schistose at their sides and the limestones again on the outside of these; and this he conceived would prove a general law in the formation of all chains composed chiefly of primary rocks.

In his "Travels in Russia," in 1793 and 1794, he made many geological observations on the recent strata near the Volga and the Caspian and adduced proofs of the greater extent of the latter sea at no distant era in the earth's history. His memoir on the fossil bones of Siberia attracted attention to some of the most remarkable phenomena of Geology. He stated that he had found a rhinoceros entire in the frozen soil, with its skin and flesh. An elephant found afterward in a mass of ice on the shore of the North Sea removed all doubts as to the accuracy of such a remarkable discovery. Quirini, in 1676, was the first writer who ventured to maintain that the universality of the Noachian cataclysm ought not to be insisted upon.

The great mathematician Leibnitz published his "Protogoea" in 1680. He imagined this planet to have been originally a burning luminous mass, which ever since its creation has been undergoing refrigeration. When the outer crust had cooled down sufficiently to allow the vapors to be condensed they fell and formed a universal ocean, covering the loftiest mountains and investing the whole globe. The crust, as it consolidated from a state of fusion, assumed a vesicular and cavernous structure, and being rent in some places, allowed the water to rush into the subterranean hollows, whereby the level of the primeval ocean was lowered. The breaking in of these caverns is supposed to have given rise to the dislocated and deranged position of the strata, "which Steno had described," and the same disruptions communicated violent movements to the incumbent waters, whence great inundations ensued. The waters, after they had been thus agitated, deposited their sedimentary matter during intervals of quiescence, and hence the various stony and earthy strata.

Robert Hooke (1635-1703) was one of the most brilliant, ingenious and versatile intellects of the seventeenth century. Among the many subjects to which he directed his attention and on which his remarkable powers of acute observation and sagacious reflection enabled him to cast light, some of the more important problems of Geology must be numbered. In 1705 appeared the "Posthumous Works of Robert Hooke, M.D.," which contained a "Discourse on Earthquakes."

He accounts for the shells found in mountains by saying that such things may be due to the action of earthquakes, "which have turned plains into mountains and mountains into plains, seas into land and land into seas, made rivers where there were none before and swallowed up others that formerly were, and which, since the creation of the world, have brought many great changes on the superficial parts of the earth and have been the instruments of placing shells, bones, plants, fishes and the like in those places where, with much astonishment, we find them."

About 1690 appeared Thomas Burnet's "Theory of the Earth." The title is characteristic of the age, "The Sacred Theory of the Earth, containing an Account of the Original of the Earth and of all the general Changes which it hath already undergone, or is to undergo, till the Consummation of all Things." Even Milton had scarcely ventured in his poem to indulge his imagination so freely in painting scenes of the Creation and Deluge, Paradise and Chaos. He explained why the primeval earth enjoyed a perpetual spring before the flood, showed how the crust of the globe was fissured by "the sun's rays," so that it burst, and thus the diluvial waters were let loose from a supposed central abyss.

The celebrated naturalist, John Ray (1627-1705), participated in the same desire to explain geological phenomena by reference to causes less hypothetical than those usually resorted to. In his essay on "Chaos and Creation" he proposed a system, agreeing in its outline and in many of its details with that of Hooke, but his knowledge of natural history enabled him to elucidate the subject with various original observations. Earthquakes, he suggested, might have been the second causes employed at the Creation in separating the land from the waters and in gathering the waters together into one place.

Among the contemporaries of Hooke and Ray, John Woodward (1665-1722), a professor of medicine, had acquired the most extensive information respecting the geological structure of the crust of the earth. His systematic collection of specimens, bequeathed to the University of Cambridge and still preserved there as arranged by him, shows how far he had advanced in ascertaining the order of superposition. He conceived "the whole terrestrial globe to have been taken to pieces and dissolved at the flood and the strata to have settled down from this promiscuous mass as any earthly sediments from a fluid." Ray immediately, by the undeniable evidences adduced from fossil deposits, disproved the unfounded nature of this assertion.

An illustrious observer in the geological domain appeared in Antonio Vallisneri (1661-1730), professor of medicine in Padua. In the course of his journeys he had opportunities of seeing much of the geology of his native country and of forming a clearer conception of the fossiliferous formations of the great central mountain-chain than any one had done before him. His works were rich in original observations.

He attempted the first general sketch of the marine deposits of Italy, their geographical extents and most characteristic organic remains. In his treatise "On the Origin of Springs," he explained their dependence on the order and often on the dislocations of the strata and reasoned philosophically against the opinions of those who regarded the disordered state of the earth's crust as exhibiting signs of the wrath of God for the sins of man.

Altho reluctant to generalize on the rich materials accumulated in his travels, Vallisneri had been so much struck with the remarkable continuity of the more recent marine strata, from one end of Italy to the other, that he came to the conclusion that the ocean formerly extended over the whole earth, and after abiding there for a long time, had gradually subsided.

The last and not the least of the cosmogonists was G. L. Leclerc de Buffon (1707-1788), one of the greatest pioneers, who figured so conspicuously in the history of France. At first interested in Physics and Mathematics, he gradually broadened his field of observation, taking in the whole realm of Nature. He adopted the theory of an original volcanic nucleus, together with the universal ocean of Leibnitz. By this aqueous envelope the highest mountains were once covered. Marine currents then acted violently and formed horizontal strata by washing away solid matter in some parts and depositing it in others; they also excavated deep submarine valleys. The level of the ocean was then depressed by the entrance of a part of its waters into subterranean caverns, and thus some land was left dry.

Soon after the publication of his "Natural History," in which was included his "Theory of the Earth," he received an official letter (dated January, 1751) from the Sorbonne, or Faculty of Theology in Paris, informing him that fourteen propositions in his works "were reprehensible and contrary to the creed of the Church." The first of these obnoxious passages, and the only one relating to geology, was as follows: "The waters of the sea have produced the mountains and valleys of the land; the waters of the heavens reducing all to a level, will at last deliver the whole land over to the sea, successively prevailing over the land, will leave dry new continents like those which we inhabit."

Buffon was invited by the college in courteous terms to send in an explanation, or rather a recantation, of his unorthodox opinions. To this he submitted, and a general assembly of the faculty having approved of his "Declaration," he was required to publish it in his next work.

The grand principle which Buffon was called upon to renounce was simply this: "That the present mountains and valleys of the earth were due to secondary causes, and that the same causes will in time destroy all the continents, hills and valleys and reproduce others like them." Now, whatever may be the defects of many of his views, it is no longer controverted that the present continents are of secondary origin. The doctrine is as firmly established as the earth's rotation on its axis, and that the land now elevated above the level of the sea will not endure forever is an opinion which gains ground daily in proportion as experience of the changes now in progress is enlarged.

Tagioni (1751) opposed Buffon in his theory regarding the origin of valleys. Buffon attributed them principally to submarine currents, while the Tuscan naturalist labored to show that both the larger and smaller valleys of the Apennines were excavated by rivers and floods, caused by the bursting of the barriers of lakes after the retreat of the ocean. He was a contemporary of Werner, who ushers in a new era.

CHAPTER IV

LAYING THE ROCKS BARE

WITH the freeing of geological study from the bondage of the Middle Ages, there came a new enthusiasm and a determined spirit to discountenance speculation and to seek untiringly in the field and in the laboratories after new observations, new truths. Interest was directed, in the first place, toward the investigation and description of the accessible parts of the earth's crust. The composition and arrangement of the strata were studied with enthusiasm. The bolder inquirers ventured into wild recesses of mountain-chains and climbed snowy peaks, whose difficulties had hitherto been thought insurmountable; travelers explored the uninhabited plains of Siberia, the remote mountain-ranges of Asia and America and brought home with them new scientific material and observations of the highest importance for comparative research. Scientific research supplanted misty supposition.

Together with this arose the realization of the value of understanding the works of the geologists of the past. For the first time a History of Geology became possible. As Sir Archibald Geikie said: "In no department of natural knowledge is the adoption of this historical method more necessary and useful than it is in Geology. The subjects with which that branch of science deals are, for the most part, not susceptible of mathematical treatment. The conclusions formed in regard to them, being often necessarily incapable of rigid demonstration, must rest on a balance of probabilities. There is thus room for some difference of opinion both as to facts and the interpretation of them. Deductions and inferences which are generally accepted in one age may be rejected in the next. This element of uncertainty has tended to encourage speculation. Moreover, the subjects of investigation are themselves often calculated powerfully to excite the imagination.

"The story of this earth since it became a habitable globe, the evolution of its continents, the birth and degradation of its mountains, the marvelous procession of plants and animals which, since the beginning of time, has passed over its surface—these and a thousand cognate themes with which Geology deals, have attracted numbers of readers and workers to its pale, have kindled much general interest and awakened not a little enthusiasm. But the records from which the chronicle of events must be compiled are sadly deficient and fragmentary. The deductions which they suggest ought frequently to be held in suspense from want of evidence. Yet with a certain class of minds fancy comes in to supply the place of facts that fail. And thus Geology has been encumbered with many hypotheses and theories which, plausible as they might seem at the time of their promulgation, have one by one been dissipated before the advance of fuller and more accurate knowledge. Yet before their overthrow it may often be hard to separate the actual ascertained core of fact within them from the mass of erroneous interpretation and unfounded inference that forms most of their substance."

The Modern Period begins with the advent of a man who bulks far more largely in the history of Geology than any of those with whom up to the present we have been concerned—a man who wielded an enormous authority over the mineralogy and geology of his day. Through the loyal devotion of his pupils, he was elevated even in his lifetime into the position of a kind of scientific pope, whose decisions were final on any subject regarding which he chose to pronounce them. During the last quarter of the eighteenth century by far the most notable figure in the ranks of those who cultivated the study of minerals and rocks was unquestionably Abraham Gottlob Werner (1749-1817). The vast influence which this man wielded arose mainly from his personal gifts and character and especially from the overmastering power he had of impressing his opinions upon the convictions of his hearers.

Werner was born in 1749 at Wehran, in Upper Lupatia, of a family which had long been interested in the iron industry. Thus from infancy he was in intimate contact with people interested in topics akin to Geology. He early became interested in mineralogy and his tendency in this direction was encouraged by his father. The latter desired his assistance in the smelting houses at Wehran, but the boy's ambition to devote himself to minerals had taken too deep root, and he decided to go to the Riding Academy at Freiberg. He was a most ardent student and all his spare moments were spent in neighboring mines. In 1771 he went to the University of Leipzig, where he prosecuted the study of law for two years, but eventually returned to his first love, mineralogy. When only 25 years of age he published a book on minerals, then a wonder of arrangement, largely as a result of which he was appointed to the post of professor of mineralogy in the School of Mines at Freiberg, where he had formerly studied.

His manner of discourse also was so attractive and stimulating that he riveted the attention of his pupils, incited them to pursue the studies that he loved and fired them with a desire to apply his methods. Ostensibly he had to teach mineralogy—a science which in ordinary hands can hardly be said to evoke enthusiasm. But Werner's mineralogy embraced the whole of Nature, the whole of human history, the whole interests and pursuits and tendencies of mankind. From a few pieces of stone, placed almost at random on the table before him he would launch out into an exposition of the influence of minerals and rocks upon the geography and topography of the earth's surface. He would contrast the mountainous scenery of the granites and schists with the tamer landscapes of the sandstones and limestones. Tracing the limits of these contrasts of surface over the area of Europe, he would dwell on their influence upon the grouping and characteristics of the nations. He would connect, in this way, his specimens with the migration of races, the spread of languages, the progress of civilization. He would show how the development of the arts and industries of life had been guided by the distribution of minerals, how campaigns, battles and military strategy as a whole had been dependent on the same course. The artist, the politician, the historian, the physician, the warrior were all taught that a knowledge of mineralogy would help them to success in their several pursuits. It seemed as if the most efficient training for the affairs of life were obtainable only at the Mining School of Freiberg.

The first feature of his grasp, distinguishable in every part of his life and work, was his overmastering sense of orderliness and method. When Werner entered upon his mineralogical studies the science of minerals was an extraordinary chaos of detached observations and unconnected pieces of knowledge. But his very first essay began to put it into order, and by degrees he introduced into it a definite methodical treatment, doing for it very much what Linnaeus had done some years before for botany. Like that great naturalist, he had to invent a language to express with precision the characters which he wished to denote, so that mineralogists everywhere could recognize them. For this purpose he employed his mother tongue and devised a terminology which, tho artificial and cumbrous, was undoubtedly of great service for a time. Uncouth in German, it became almost barbarous when translated into other languages. What would the modern English-speaking student think of a teacher who taught him, as definite characters, that a mineral could be distinguished as "hard or semihard," "soft or very soft," as "very cold, cold, pretty cold or rather cold," as "fortification-wise bent," as "indeterminate curved lamellar," as "common angulo-granular" or as "not particularly difficultly frangible"?

Werner arranged the external characters of minerals in so methodical a way that they could readily be applied in the practical determination of species. Yet strangely enough he neglected the most important of them all—that of crystalline form. From the individual minerals he proceeded to the consideration of their distribution and the character and origin of the different rocks in which they occur. To this branch of inquiry he gave the name of geognosy, or knowledge of the earth, and he defined it as the science which reveals in a methodical order the terrestrial globe as a whole and more particularly the layers of mineral matter whereof it consists, informing as to the position and relations of these layers to each other, and enabling the formation of some idea of their origin. The term geology had not yet come into use, nor would either Werner or any of his followers have adopted it as a synonym for the "geognosy" of the Freiberg school. They prided themselves on their close adherence to fact as opposed to theory. They boasted of the minuteness and precision of their master's system, and contrasted the positive results to which it led with what they regarded as the vague conclusions and unsupported or idle speculations of other writers. Werner arranged the crust of the earth into a series of "formations," which he labeled and described with the same precision that he applied to the minerals in his cabinet.

But never in the history of science did a stranger hallucination arise than that of Werner and his school when they supposed themselves to discard theory and build on a foundation of accurately ascertained fact. Neither was a system devised in which theory was more rampant; theory, too, unsupported by observation, and, as is now known, utterly erroneous.

One of the fundamental postulates of the Wernerian doctrines was the existence of what were termed universal formations. When he elaborated his system, Werner had never been out of Saxony and the immediately adjacent regions. His practical knowledge of the earth was, therefore, confined to what he could see there, and so little was then known of the geological structure of the globe as a whole that he could not add much to his acquaintance with the subject by reading what had been observed by others, tho there can be little doubt that he stood greatly indebted to Lehmann and Füchsel. With this slender stock of acquirement, he adopted the old idea that the whole globe had once been surrounded with an ocean of water, at least as deep as the mountains are high, and he believed that from this ocean there were deposited by chemical precipitation the solid rocks which now form most of the dry land. He taught that these original formations were universal, extending round the whole globe, tho not without interruption, and that they followed each other in a certain order.

Werner affirmed that the first formed rocks were entirely of chemical origin, and he called them Primitive, including in them granite, which was the oldest, gneiss, mica-slate, clay-slate, serpentine, basalt, porphyry, and concluding with syenite as the youngest. Succeeding these came what he afterward separated as the Transition Rocks, consisting chiefly of chemical productions (graywacke, graywacke-slate and limestone), but comprising the earliest mechanical depositions and indicating the gradual lowering of the level of the universal ocean. Still newer, and occupying, on the whole, lower positions, marking the continued retirement of the waters, were the Floetz Rocks, composed partly of chemical, but chiefly of mechanical sediments, and including sandstone, limestone, gypsum, rock-salt, coal, basalt, obsidian, porphyry and other rocks. Latest of all came the Alluvial series, consisting of recent loams, clays, sands, gravels, sinters and peat.

This system was not put forward tentatively as a suggestion toward a better comprehension of the history of the earth. It was announced dogmatically as a body of ascertained truth about which there could be no further doubt or dispute. "In recapitulating the state of our present knowledge," Werner declares with his characteristic emphasis, "it is obvious that we know with certainty that the floetz and primitive mountains have been produced by a series of precipitations and depositions formed in succession from water which covered the globe. We are also certain that the fossils which constitute the beds and strata of mountains were dissolved in this universal water and were precipitated from it; consequently the metals and minerals found in primitive rocks and in the beds of floetz mountains were also contained in this universal solvent and were formed from it by precipitation.

"We are still further certain that at different periods different fossils have been formed from it, at one time earthy, at another metallic minerals, at a third time some other fossils. We know, too, from the position of these fossils, one above another, to determine with the utmost precision which are the oldest and which the newest precipitates. We are also convinced that the solid mass of our globe has been produced by a series of precipitations formed in succession (in the humid way); that the pressure of the materials thus accumulated was not the same throughout the whole; and that this difference of pressure and several other concurring causes have produced rents in the substance of the earth, chiefly in the most elevated parts of its surface. We are also persuaded that the precipitates taking place from the universal water must have entered into the open fissures which the water covered. We know, moreover, for certain that veins bear all the marks of fissures formed at different times; and, by the causes which have been assigned for their formation, that the mass of veins is absolutely of the same nature as the beds and strata of mountains, and that the nature of the masses differs only according to the locality of the cavity where they occur. In fact, the solution contained in its great reservoir (that excavation which held the universal water) was necessarily subjected to a variety of motion, while that part of it which was confined to the fissures was undisturbed and deposited in a state of tranquillity its precipitate."

It would be difficult to cite from any other modern scientific treatise a series of consecutive sentences containing a larger number of dogmatic assertions, of which almost every one is contradicted by the most elementary facts of observation. The habit of confident affirmation seems to have blinded Werner to the palpable absurdity of some of his statements. For example, the theory of a universal, primeval ocean occupying an excavation that was so deep that it overtopped the highest mountains was superficially most ridiculous. If this ocean covered the entire globe, where was the excavation and how did this deep ocean disappear? It may be interesting to know how Werner explained this natural question, but none of his writings satisfactorily answer it. In one place he thinks it possible that "one of the celestial bodies which sometimes approach near to the earth may have been able to withdraw a portion of our atmosphere and of our ocean." But if once the waters were abstracted, how were they to be brought back again so as to cover all the hills on which his highest Floetz formations were deposited?

One might have thought that having disposed of the universal ocean, even in this rather peremptory fashion, the Wernerians would have been in no hurry to call it back again and set the same stupendous and inexplicable machinery once more going. But the exigencies of their theory left them no choice. Having determined, as an incontrovertible fact, that certain rocks had been deposited as chemical precipitates in a definite order from a universal ocean, when these philosophers, as their knowledge of Nature increased, found that some of these so-called precipitates occurred out of their due sequence and at much higher altitudes than had been supposed, they were compelled to bring back the universal ocean and make it rise high over hills from which it had already receded. Not only had they to call up the vasty deep, but they had to endow it with rapid and even tumultuous movement as it swept upward over forest-clothed lands. Having raised it as high as their so-called Floetz formations extended, and having allowed its waters to settle and deposit precipitates of basalt and greenstone, they had to hurry it away again to the unknown regions where it still remains.

So early as 1768, before Werner had commenced his mineralogical studies, Raspe had truly characterized the basalts of Hesse as of igneous origin. Arduino had pointed out numerous varieties of traprock in the Vicentine as analogous to volcanic products and as distinctly referable to ancient submarine eruptions. Desmarest had, in company with Fortis, examined the Vicentine in 1766 and confirmed Arduino's views. In 1772 Banks, Solander and Troil compared the columnar basalt of Hecla with that of the Hebrides. Collini, in 1774, recognized the true nature of the igneous rocks on the Rhine between Andernach and Bonn. In 1775 Guettard visited the Vivarais and established the relation of basaltic currents to lavas. Lastly, in 1779, Faujas published his description of the volcanoes of the Vivarais and Velay and showed how the streams of basalt had poured out from craters which still remain in a perfect state.

Leopold von Buch (1774-1852) was the most illustrious of the geologists taught by Werner. He was born in the Castle of Stolpe in Pomerania, the son of a nobleman with considerable property. While still a boy he displayed a passionate love of scientific inquiry, and his fondness for chemical and physical mineralogical studies led him to select the Mining Academy of Freiberg for his collegiate course. While there Alexander von Humboldt and Freiesleben were among his fellow students, and with them he formed close ties of friendship. He made his home for nearly three years (1790-1793) with Professor Werner, for whom he entertained the deepest sentiments of reverence and friendship, and these were in no way altered when, in after years, some of his opinions began to diverge from the teaching of Werner.

Von Buch examined the raised beaches and the terraces of Scandinavia and came to the conclusion that the Swedish coast was slowly rising above the level of the sea. In this he agreed with the opinion that had been formed by Playfair with regard to the raised beaches of Scotland. In 1809 Von Buch was chiefly engaged in mineralogical and geological researches in the Alps. Meanwhile great interest had been roused throughout Europe by the results of Von Humboldt's brilliant volcanic studies in Central and South America, and Von Buch determined to make a special study of some volcanic district.

Accompanied by the English botanist, Charles Smith, he visited the Canary Isles and in 1815 convinced himself that they had been the center of intense volcanic activity. In his famous monograph, "A Physical Description of the Canary Islands," published in 1825, he enunciated his hypothesis of upheaval craters and distinguished between "centers" and "bands" of volcanic action. In 1817 he traveled to Scotland and visited Staffa and the Giant's Causeway. When he again returned to the Alps he renounced the Wernerian doctrines of the origin of basalt and other volcanic rocks and ascribed the upheaval of the Alps to the intrusion of igneous rocks.

At the time when Werner was in the zenith of his fame, during those seventies and eighties of the eighteenth century when young geologists were flocking to hear the wisdom from the lips of the prophet of geognosy in Freiberg, a private gentleman, living quietly in Edinburgh, was deliberating and writing a work on the earth's surface that will live forever in the annals of Geology as one of its noblest classics. His work and that of his contemporaries is ably reviewed by Karl von Zittell.

James Hutton (1726-1797), the author of the famous "Theory of the Earth," was the son of a merchant and received an excellent education at the High School and University of his native city. His strong bent for chemical science induced him to select medicine as a profession. He studied at Edinburgh, Paris and Leyden and took his degree at Leyden in 1749, but on his return to Scotland he did not follow out his profession. Having inherited an estate in Berwickshire from his father, he went to reside there and interested himself in agriculture and in chemical and geological pursuits.

From his early days he had always taken a delight in studying the surface forms and rocks of the earth's crust and had lost no opportunity of extending his geological knowledge during frequent journeys in Scotland, England, in northern France and the Netherlands. At last Hutton set himself to the work of shaping his ideas into a coherent, comprehensive form and in 1785 read his paper on the "Theory of the Earth" before the Royal Society of Edinburgh. The publication of the work attracted little favorable notice, partly due to the involved, unattractive style of writing; in larger measure, however, it was due to the fact that the learning of the schools had no part in Hutton's work. Hutton's thoughts had been borne in upon him direct from nature; for the best part of his life he had conned them, tossed them in his mind, tested them and sought repeated confirmation in nature before he had even begun to fix them in written words or cared to think of anything but his own enjoyment of them. Hutton's work was projected upon a plane half a century beyond the recognized geology of his own time. Hutton's audience of geologists had to grow up under other influences than polemical discussions between Neptunists and Plutonists and had to learn from Hutton himself how to tap the fountain of science at its living source.

In 1793 a Dublin mineralogist, Kirwan, attacked Hutton's work, and the great Scotsman, now advanced in years, resolutely determined to revise his work and do his best by it. Valuable additions were made and the subject-matter brought under more skilful treatment. In 1795 the revised work appeared at Edinburgh in independent form and in two volumes. It was his last effort; he died two years later from an internal disease which had overshadowed the closing years of his life.

The original treatise of Hutton is divided into four parts. The first two parts discuss the origin of rocks. The earth is described as a firm body, enveloped in a mantle of water and atmosphere and which has been exposed during immeasurable periods of time to constant change in its surface conformation. The events of past geologic ages can be most satisfactorily predicted from a careful examination of present conditions and processes. The earth's crust, as far as it is open to investigation, is largely composed of sandstones, clays, pebble deposits and limestones that have accumulated on the bed of the ocean. The limestones represent the aggregated shells and remains of marine organisms, while the other deposits represent fragmental material transported from the continents. In addition to these sedimentary deposits of secondary origin there are primary rocks, such as granite and porphyry, which, as a rule, underlie the aqueous deposits. In earlier periods the earth presented the aspect of an immense ocean, surmounted here and there by islands and continents of primary rock. There must have been some powerful agency that converted the loose deposits into solid rock and elevated the consolidated sediments above the level of the sea to form new islands and continents.

According to Hutton, this agency could only have been heat; it could not have been water, since the cement material (quartz, felspar, fluorine, etc.) of many sedimentary rocks is not readily soluble in water and could scarcely have been provided by water. On the other hand, most solid rocks are intermingled with silicious, bituminous or other material which may be melted under the influence of heat. This suggested to Hutton his theory that at a certain depth the sedimentary deposits are melted by the heat to which they are subjected, but that the tremendous weight of the superincumbent water causes the mineral elements to consolidate once more into coherent rock-masses. He applied this theory of the melting and subsequent consolidation of rock-material universally to all pelagic and terrestrial sediments.

In the third part it is shown that the present land areas of the globe are composed of rock strata which have consolidated during past ages in the bed of the ocean. These are said to have been pushed upward by the expansive force of heat, while the strata have been bent and tilted during the upheaval. Hutton next describes the occurrence of crust fissures both during the consolidation of the rock and during the elevation of large areas and the subsequent inrush of molten rock or mineral ores into the fissures. He regards volcanoes as safety-valves during upheaval, which by affording exit at the surface for the molten rock-magma and superheated vapors prevent the expansive forces from raising the continents too far.

The evidences of volcanic eruption in the older geological epochs are next discussed. Hutton expresses the opinion that during the earlier eruptions the molten rock material spread out between the accumulated sediments or filled crust fissures, but did not actually escape at the surface; consequently that the older rock-magmas had solidified at great depths in the crust and under enormous pressure of superincumbent rocks. He calls the older eruptive rocks "subterraneous lavas" and includes among them porphyry and the whinstones (*eq.* trap-rock, greenstone, basalt, wacke, amygdaloidal rocks). Granite was also added in a later treatise. Hutton points out that the subterraneous lavas have a crystalline structure, whereas those that solidify at the surface have a slaggy or vesicular structure.

In the fourth part Hutton concentrates attention on the preëxistence of older continents and islands from which the materials composing more recent land areas must have been derived. He likewise discusses the evidences of preëxisting pelagic, littoral and terrestrial faunas from which existing faunas must have sprung. But, he continues, the existence of ancient faunas assumes an abundant vegetation, and direct evidence of extinct floras is presented in the coal and bituminous deposits of the Carboniferous and other epochs. Other evidence is afforded in the silicified trunks of trees that occasionally are found in marine deposits and have clearly been swept into the sea from adjacent lands.

Hutton then sets forth, in passages that have become classic in geological science, the slow processes of the subaerial denudation of land surfaces. He describes the effects of atmospheric weathering, of chemical decomposition of the rocks, of their demolition by various causes and the constant attrition of the soil by the chemical and mechanical action of water. He elucidates with convincing clearness the destructive physical, chemical and mechanical agencies that effect the dissolution of rocks, the work of running water in transporting the worn material from the land to the ocean, the steady subsidence of coarser and finer detritus that goes on in seas and oceans, lakes and rivers and the slow accumulation of the deposits to form rock strata. Hutton impresses upon his readers the vastness of the geological eons necessary for the completion of any such cycle of destruction and construction. In proof of this, he calls attention to the comparative insignificance of any changes that have taken place in the surface conformation of the globe within historic time.

Hutton was thus the great founder of physical and dynamical geology; he for the first time established the essential correlation in the processes of denudation and deposition; he showed how, in proportion as an old continent is worn away, the materials for a new continent are being provided, how the deposits rise anew from the bed of the ocean, and another land replaces the old in the eternal economy of nature. The outcome of Hutton's argument is expressed in his words "that we find no vestige of a beginning—no prospect of an end."

When Hutton's theory of the earth's structure is compared with that of Werner and other contemporary or older writers the great feature which distinguishes it and marks its superiority is the strict inductive method applied throughout. Every conclusion is based upon observed data that are carefully enumerated, no supernatural or unknown forces are resorted to and the events and changes of past epochs are explained from analogy with the phenomena of the present age.

Hutton's explanation of the uprising of continents, owing to the expansive force of the subterranean heat, was not altogether new nor was it satisfactory. Neither had Hutton any clear conception of the significance of fossils as affording evidence of a gradual evolution. Yet in spite of these disadvantages, Hutton's "Theory of the Earth" is one of the masterpieces in the history of geology. Hutton's genius first gave to geology the conception of calm, inexorable nature working little by little—by the rain-drop, by the stream, by insidious decay, by slow waste, by the life and death of all organized creatures—and eventually accomplishing surface transformations on a scale more gigantic than was ever imagined in the philosophy of the ancients or the learning of the schools.

Hutton's scientific spirit and genial personality won for him many friends and adherents among the members of the Edinburgh academy. The most distinguished of these were Sir James Hall and the mathematician John Playfair. Hall (1762-1831) contested the validity of the opinion held by some of Hutton's opponents, that the melting of crystalline rocks would only yield amorphous glassy masses. Hall followed experimental methods; he selected different varieties of ancient basalt and lavas from Vesuvius and Etna, reduced them to a molten state and allowed them to cool. At first he arrived only at negative results, as vitreous masses were produced; but he then retarded the process of cooling and actually succeeded in obtaining solid, crystalline rock material. By regulating the temperature and the time allowed for the cooling and consolidation, Hall could produce rocks varying from finely to coarsely crystalline structure. And he therefore proved that under certain conditions crystalline rock could, as Hutton had said, be produced by the cooling of molten rock-magma.

Hall then put to the test Hutton's further hypothesis, that limestone also was melted and re-crystallized in nature. To this hypothesis the objection had been made that the carbonic acid gas must escape if limestone were brought to a glowing heat and the material would be converted into quicklime. This was Hall's first experience; then he devised another experiment. He introduced chalk or powdered limestone into porcelain tubes or barrels, sealed them and brought them to a very high temperature. The carbon dioxide gas could not escape under these conditions. The calcareous material was thus subjected to the enormous pressure of the imprisoned air and converted into a granular substance resembling marble.

Hall also conducted experiments on the bending and folding of rocks. He spread out alternate horizontal layers of cloth and clay, placed a weight upon them and subjected them to strong lateral pressure. These and similar experiments have been often repeated within recent years, and it is well known that in this way phenomena of deformation can be artificially produced which bear the closest resemblance to the phenomena of rock deformation under natural conditions. In his desire to vindicate Hutton's theory, Hall became himself one of the great founders of experimental geology.

At the same time John Playfair (1748-1819), whose interest in geology had been roused by Hutton's companionship, became the enthusiastic exponent of Hutton's theory. It was Playfair's literary skill that opened the eyes of scientific men to the heritage Hutton had left for them. He did for Hutton's teaching what fifty years after was done for Darwin's doctrines by the gifted Huxley.

Playfair's "Illustration of the Huttonian Theory" is a lucid exposition of that theory in the form of twenty-six ample discussive notes. Playfair's work differs in no essential point from the views held by his master and friend, but many subjects which receive a subordinate treatment in the "Theory of the Earth" are brought into prominence by Playfair and placed for the first time on a firm scientific basis. His treatment of valley and lake erosion is extremely able. And Playfair was the first geologist who realized that the huge erratic blocks might have been carried to their present position by former glaciers. His insight in this respect would alone have won for him a lasting fame, for the erratics on Alpine slopes and plains had long been observed by geologists and an explanation vainly sought.

CHAPTER V

DEVELOPMENTS OF MODERN GEOLOGICAL KNOWLEDGE

WITH Hutton's work as a basic point Geology took new life. The theory in the main was sound; it remained but to classify the results of the past and to prepare for the reception of the observations of the future. The nineteenth century witnessed the great development of the processes of the earth's formation which stratigraphical geology sets forth.

Jean-Baptiste Pierre Antoine de Monet, Chevalier de Lamarck (1744-1829), came of an ancient but somewhat decayed family and was born in a village of Picardy as the eleventh and youngest child of the Seigneur de Béarn. The earlier part of his career was devoted first to soldiering, then to Botany and then to Zoology. Though Lamarck wrote little on Geology, the extent to which he had pondered over the problems of the science, which in his time had hardly taken definite shape, is well illustrated by the little volume which he published in 1802 under the title of "Hydrogéologie." He recognized that nothing can ultimately resist the alternating influence of wetness and drought, combined with that of heat and cold, and that the disintegration of mineral substances by these atmospheric conditions prepares the way for the erosive action of running water in all its various forms.

To him it was clear that every mountain which had not been erupted by volcanic action or some other local catastrophe, had been cut out of a plain, so that the mountain summits represent the relics of that plain, save in so far as its level has been lowered in the general degradation. He admits that in many mountains the component strata are often vertical or highly inclined. But he will not on that account believe in any universal catastrophe, such as had been demanded by many previous writers and was still loudly advocated in his own time by his fellow-countryman, Cuvier.

Lamarck conceived the ocean basin to owe its existence and preservation to the perpetual oscillation of the tides and partly also to a general westerly movement of the water. He supposed the tidal oscillation to be a gigantic force which has actually eroded the basin and now prevents it from being shallowed, through the deposit of land-derived sediment, by continually scouring this sediment out and casting it up along the more sheltered shores of the land. No one before his day had been able to follow so clearly the successive stages through which organic remains pass until they become crystalline stone, presenting no trace of their original organic structure. During the last ten years of his long life he suffered from total blindness and had to rely on the affectionate devotion of his eldest daughter for the completion of such works as he had in progress before his eyesight failed. The world is becoming more conscious now of what it owes to the genius of this illustrious naturalist. Among those students of science who have most reason to cherish his memory geologists should look back gratefully to his services in starting the science of paleontology, in propounding the doctrine of evolution and in affirming with great insight some of the fundamental principles of modern geology.

Georges Cuvier (1769-1832), a French naturalist and founder of the science of comparative anatomy, effected a great and notable advance in the science of Paleontology. It is to Cuvier that the world owes the first systematic application of that science of comparative anatomy, which he himself did so much to place upon a sound basis, to the study of the bones of fossil animals. He demonstrated that extinct animals could be "reconstructed" from fragmentary remains by applying the law of "correlation of growth." But it is true, as pointed out by Professor Huxley, that he placed more confidence and security in this law than its empiric nature and exceptions would justify.

Cuvier in his work on the geology of the Paris basin was greatly assisted by his friend, Alexandre Brongniart. Brongniart was early trained in scientific pursuits. In 1807 he published a treatise on mineralogy at the Jardin des Plantes and in 1808 appeared the work on the Paris basin. Cuvier and Brongniart drew up a systematic table of the succession of stratigraphical horizons in accordance primarily with the sequence of the deposits in the ground and with the particular fossils characterizing each group of deposits; the varieties of rock and the thicknesses and distribution of different deposits were also fully considered and carefully mapped.

Omalius d'Halloy (1783-1875), the Belgian geologist, made an examination of the formations in Auvergne, Velay and in parts of Italy and Germany, and in all cases proved conclusively that the fossil remains had been imbedded in the deposits of fresh-water marshes and were not remains which had been accidentally swept into marine deposits. The Belgian geologist supplemented the observations of Cuvier and Brongniart with great success.

Early in his career D'Halloy had regarded the position of the strata, their horizontal, slightly or highly inclined, or vertical position, of great importance in determining the age of the strata. He thought the horizontal strata corresponded to Werner's "Flötz formations" and all inclined strata to Werner's "Transitional formations." But his subsequent visit to the Alps and Jura mountains caused him to modify these views.

The fearful earthquake which destroyed Lisbon in 1755 was made the subject of a large number of scientific inquiries into the cause of earthquakes. William Stukeley's theory, attributing earthquakes to electrical disturbances, gained a certain amount of support abroad. Another Englishman, Rev. John Mitchell, suggested that sudden expansion of vapors enclosed in fissures and cavities of the earth's crust caused earthquakes and volcanoes, the upheaval of mountain systems and the deformation of rocks.

In 1760 he published a series of observations on earthquakes and mountain structure. This paper was accompanied by an ideal section through a mountain system, showing a central core composed of the crystalline massive rocks, on either side a succession of uptilted and upheaved strata covered in their turn by younger, slightly tilted or horizontal deposits composing the neighboring plains. Mitchell, however, did not draw any general conclusions, yet he deservedly ranks as the great pioneer of the modern science of Seismology.

Another English observer was John Whitehurst (1713-1788), who published in 1778 an "Inquiry into the Original State and Formation of the Earth." This work was the last effort of the fantastic English school of cosmogonists. Amid absurd speculations as to the condition of chaos and other equally visionary topics, he wrote well on organic remains and showed that he clearly grasped the stratigraphical succession of the formations in Derbyshire and other parts of England. "The strata invariably follow each other," he remarks, "as it were, in alphabetical order," and though they may not be alike in all parts of the earth, nevertheless "in each particular part, how much soever they may differ, yet they follow each other in a regular succession." He was one of the many who were interested in the origin of the basaltic pillars of the Giants' Causeway and who endeavored to interpret their origin.

One of the most active and interesting of those who devoted themselves with ardor to the study of the Italian volcanoes was Gratet de Dolomieu (1750-1801). His attention was especially drawn to the active and extinct volcanoes of the Mediterranean basin. As far back as 1776 he made the announcement that he had found in Portugal evidence of volcanoes older than certain mountains of limestone—a statement which he supplemented in 1784 with further evidence from Sicily, proving the intercalation of ancient lavas among stratified deposits. Dolomieu confirmed the igneous origin of basalt rock, regarding it as a variety of lava for the most part associated with submarine eruptions. His name is perpetuated in the name of the "Dolomites," given to the beautiful district in South Tyrol, south of the Puster Valley.

Elie de Beaumont was another scientific Frenchman who interested himself in mountains. He was one of the most enthusiastic adherents of the Vulcanist doctrines. Toward the end of an article on mountains, which appeared in the Annales of the French Academy, are a few remarks on mountain structure. Brief although they are, the remarks on the influence of the slow cooling of the earth on surface conformation and the origin of furrows and fissures are at once recognized by a reader of the present day as the starting-point of the modern views on mountain structure. Later appeared his three volume treatise on mountain systems. He points out that in virtue of the continued cooling of the planet the radius is shortened and the crust is affected by a general centripetal movement; that is, the volume of the globe becoming less, the crust is drawn in toward the center of gravity.

Delesse meanwhile had calculated 1,340 meters as the amount by which the earth's radius had already been shortened; in other words, the earth's crust in the course of the geological epochs had approached the earth's center by a distance about equal to the height of Chimborazo or the Himalayas above sea-level.

William Smith (1769-1839), an English engineer, was the first to recognize the importance of fossils in their full significance as a means of determining the relative age of strata. Born in a county that was unusually rich in fossil remains, he had in his boyhood abundant opportunity of observing and collecting. For twenty-five years he continued his investigations in all parts of England, entered his observations in colored geological maps and compiled them from time to time in the form of tables or as explanatory notes to his maps.

About 1800 he began the preparation of a geological map of England and Wales on a scale of five miles to one inch, which occupied nearly fifteen years of his life and which was supplemented by separate maps of the counties published in color on twenty-one sheets. Smith's map is the first attempt to represent on a large scale the geological relations of any extensive tract of ground in Europe. It was a magnificent achievement and was the model of all subsequent geological maps. For English Geology, the publication of the map was the starting-point of a new régime. The Geological Society of London conferred upon him the Wollaston medal, and he well deserves to be called the "Father of English Geology."

There is yet another name that deserves to be remembered in any review of the early efforts to group the Secondary formations—that of Thomas Webster (1773-1844). As far back as 1811 this clever artist and keen-eyed geologist began a series of investigations of the coast sections of the Isle of Wight and of Dorset and continued them for three years. He clearly defined each of the leading subdivisions of the Cretaceous series and prepared the way for the admirable later and more detailed works of William Henry Fitton (1780-1861), to whom Geology is indebted for the first detailed and accurate determination of the succession of strata and their distinctive fossils, from the base of the Chalk down into the Oolites, in the south of England and the neighboring region in France. More particularly he showed the relations and importance of the Greensand formations, his memoirs on which are now among the classics of English geology.

The early progress of stratigraphical geology in Britain includes the important influence exerted by the Geological Society of London, which was founded in 1807 "to investigate the mineral structure of the earth." At that time the warfare between the Neptunists and Plutonists still continued, but there were many men interested in the study of geological subjects who were weary of the conflict of hypotheses and who would fain devote their time and energy to the accumulation of facts regarding the ancient history of the globe rather than to the elaboration of theories to explain them. A few such inquirers formed themselves into the Geological Society and soon attracted others around them until, in a few years, they had established an active institution which became a center for geological research and discussion, published the contributions of its members in quarto volumes and eventually was incorporated by royal charter as one of the leading scientific bodies of the country. This society, which has been the parent of others in different countries, continues to flourish, and its publications, extending over nearly a century, contain a record of original researches which have powerfully helped the progress of all branches of geology. Besides their papers issued by the society, some of the early members published separate works which greatly advanced the cause of their favorite science. Among these early independent treatises perhaps the most important was the "Outlines of the Geology of England and Wales" by W. D. Conybeare (1787-1857) and W. Phillips (1775-1828), which appeared in 1822. In this volume all that was then known regarding the rocks of the country, from the youngest formations down to the Old Red Sandstone, was summarized in so clear and methodical a manner as to give a definite impulse to the cultivation of Geology in England.

The amount of ascertained fact regarding the structure and history of the earth was every year increasing at so rapid a rate that it became necessary to prepare digests of it for the use of those who wished to be informed on these subjects or to keep pace with the advance of knowledge. Hence arose in different countries text-books, manuals and other general treatises wherein an account was given of the facts and principles of geological science.

But of all the English writers of general treatises on geology, the first place must undoubtedly be assigned to Charles Lyell (1797-1875), who exercised a profound influence on the geology of his time in all English-speaking countries. Adopting the principles of the Huttonian theory, says Sir Archibald Geikie, in his "Founders of Geology," he developed them until the original enunciator of them was nearly lost sight of.

"With unwearied industry he marshalled in admirable order all the observations that he could collect in support of the doctrine that the present is the key to the past. With inimitable lucidity he traced the operation of existing causes and held them up as the measure of those which have acted in bygone time. He carried Hutton's doctrine to its logical conclusion, for not only did he refuse to allow the introduction of any process which could not be shown to be a part of the present system of Nature, he would not even admit that there was any reason to suppose the degree of activity of the geological agents to have ever seriously differed from what it has been within human experience. He became the great high priest of Uniformitarianism—a creed which grew to be almost universal in England during his life, but which never made much way in the rest of Europe, and which in its extreme form is probably now held by few geologists in any country." Lyell's "Principles of Geology" will, however, always rank as one of the classics of Geology and must form an early part of the reading of every man who would wish to make himself an accomplished geologist. The last part of this work was ultimately published as a separate volume, with the title of "Elements of Geology," in which a large space was devoted to an account of the stratified fossiliferous formations. This treatise, diligently kept up to date by its author, continued during his lifetime to be the chief English exposition of its subject and the handbook of every English geologist.

Lyell's function was mainly that of a critic and exponent of the researches of his contemporaries and of a philosophical writer thereon, with a rare faculty of perceiving the connection of scattered facts with each other and with the general principles of science. As Ramsay once remarked, "We collect the data and Lyell teaches us to comprehend the meaning of them." But Lyell, though he did not, like Sedgwick and Murchison, add new chapters to geological history, nevertheless left his mark upon the nomenclature and classification of the geological record. Conceiving, as far back as 1828, the idea of arranging the whole series of Tertiary formations in four groups, according to their affinity to the living fauna, he established, in conjunction with Deshayes, who had independently formed a similar opinion, the well-known classification into Eocene, Miocene and Pliocene. The scheme was a somewhat artificial one, and the original percentages have had to be modified from time to time to accord with later discoveries, but the terms have kept their place and are now firmly planted in the geological language of all corners of the globe.

So far no complete subdivision of the immense complex of strata between the crystalline schists and the coal measures had been attempted, and it was this gigantic task that the two British geologists, Adam Sedgwick (1785-1873) and Roderick Murchison (1792-1871), set themselves to accomplish in the British area. Unfortunately the scarcity of fossils made it still impossible for Sedgwick to establish paleontological subdivisions. Murchison was more fortunate. While his colleague was engaged in the examination of the oldest group of the Transitional series Murchison began his investigation of the series in descending order from the upper members to the lower. He examined the exposures of Old Red Sandstone and the rocks immediately below it, which occur on the eastern and southern borders of Wales.

Murchison found fossils in abundance, and in a couple of years was able to lay before the Geological Society a complete paleontological sequence in the upper portion of the Transitional formations. At first Murchison had called these higher members examined by him an "Upper fossiliferous graywacke series," but in the year 1835, in compliance with the strongly expressed wish of Elie de Beaumont, he proposed the name "Silurian System" as a special designation for the upper members. And as the older members of the Transitional series examined by Sedgwick in Cumberland and North Wales could not be identified with any of the members in the Silurian system of Murchison, the term of "Cambrian Series" was proposed by Sedgwick in 1836 for these older members, and this term was accepted by Murchison.

Murchison distinguished three chief divisions in the Silurian system: Upper Silurian, comprising the Ludlow Rocks and Wenlock Limestone; Lower Silurian, comprising the Caradoc Sandstone and Llandeilo Flags; and Cambrian. He found it impossible at the time to fix a definite paleontological horizon as the lower limit of the Silurian system, and Sedgwick also could not assign any paleontological or other feature which would determine the upper limit of the Cambrian series. Nevertheless the recognition of the Silurian and Cambrian systems was one of the most important advances that have been made in stratigraphy.

The vast and varied series of rocks which have now been ascertained to underlie the oldest Cambrian strata have undergone much scrutiny during the last half century, and their true nature and sequence are beginning to be understood. The first memorable onward step in this investigation was taken in North America by William Edmond Logan (1798-1875). He recognized the existence of at least three vast systems older than the oldest fossiliferous formations. He may be said to have inaugurated the detailed study of Pre-Cambrian rocks. Subsequent investigation has shown the structure of the regions which he explored to be even more complicated and difficult than he believed it to be, but he will ever stand forward as one of the pioneers of Geology, who, in the face of incredible difficulties, first opened the way toward a comprehension of the oldest rocks of the crust of the earth.

Charles Darwin (1809-1882) contributed several valuable works to the literature of Geology. The two geological chapters in his "Origin of Species" produced a great revolution in geological thought. To most of the geologists of his day Darwin's contention for the imperfection of the geological record and his demonstration of it came as a kind of surprise and awakening. They had never realized that the history revealed by the long succession of fossiliferous formations, which they had imagined to be so full, was in reality so fragmentary.

Lord Kelvin (Sir William Thomson) (1824-1907) attributed great importance to the enormous pressure existing in the interior of the earth and the consolidation of the nucleus from this cause. He ascribed to the body of the earth a degree of rigidity intermediate between that of steel and of glass. Starting from the nebular theory, Lord Kelvin supposed that the cooled and thereby heavier masses sank inward and formed an initial central nucleus, which always extended toward the periphery as the earth's mass continued to cool, until finally almost the whole earth became rigid.

Sir Andrew Crombie Ramsay (1814-1891), the noted Scotch geologist, devoted his attention to the physical side of Geology. His dislike for Paleontology and Petrology sometimes led him into serious theoretical errors, thereby impairing the value of his work.

Suess' contributions to Geology opened up a new path in geological inquiry and laid the foundation for what is now frequently termed the "New Geology," dealing with the construction and relations of continents and mountain ranges, the dynamics of volcanoes and earthquakes, and the general movement of the earth's crust. In 1885 he began his "Antlitz der Erde," which is a masterful exposition of the relations of the dominant features of the earth's surface, and the first luminous efforts to correlate their multiform aspects and give to them their true geological expression. He was one of the recognized authorities on earthquakes and volcanoes.

Jean Louis Rodolphe Agassiz (1807-1873) was born in Switzerland, and rose to distinction by his scientific work in Europe, but he went to the United States when he was still only forty-two years of age, and spent the last twenty-seven years of his life as an energetic and successful leader of science in his adopted home. His fame as a geologist is due to the important part he took in founding the modern school of glacial geology.

Tracing the distribution of the erratic blocks above the present level of the glaciers, and far beyond their existing limits, he connected these transported masses with the polished and striated rock-surfaces which were known to extend even to the summits of the southern slopes of the Jura. He was led to conclude that the Alpine ice, now restricted to the higher valleys, once extended into the central plain, crossed it, and even mounted to the southern summits of the Jura chain.

Before Agassiz took up the question there were two prevalent opinions regarding the transport of the erratics. One of these called in the action of powerful floods of water, the other invoked the assistance of floating ice. Agassiz combated these views with great skill. But the conclusions at which he arrived seemed to most men of the day extravagant and incredible. Even a cautious thinker like Lyell saw less difficulty in sinking the whole of Central Europe under the sea, and covering the waters with floating icebergs, than in conceiving that the Swiss glaciers were once large enough to reach to the Jura." Men shut their eyes to the meaning of the unquestionable fact that, while there was absolutely no evidence for a marine submergence, the former track of the glaciers could be followed mile after mile, by the rocks they had scored and the blocks they had dropped, all the way from their present ends to the far-distant crests of the Jura.

William Nicol was a lecturer on Natural Philosophy at Edinburgh in the early part of last century. Among his inventions was the famous prism of Iceland spar that bears his name. Every petrographer will acknowledge how indispensable is this little piece of apparatus in his microscopic investigations. He may not be aware, however, that it was the same hand that devised the process of making thin slices of minerals and rocks, whereby the microscopic examination of these substances became possible. At last Henry Clinton Sorby came to Edinburgh. He soon began to put the method of preparing thin slices into practice, made sections of mica-schist, threw his whole energy into the investigation for several years, and produced at last in 1858 the well-known memoir, "On the Microscopial Structure of Crystals," which marks one of the most prominent epochs of modern geology.

At this time the discoveries of Darwin turned the attention of the world to the question of the Origin of Species, and the geologists of the world, for the third quarter of the nineteenth century, spent most of their energy along paleontological lines, and the results will be found in this volume under the descriptive heading, "Historical Geology." In this subject the zoologist and the geologist work hand in hand. The geologist assists his brother scientist by tracing the order in which the strata were deposited in which fossils were found, and the paleontologist checks up the work by showing the development in complexity of the animals to which those bones belonged.

As the nineteenth century drew to its close, and the paleontological record was seen to be well in hand, an entirely new set of problems was undertaken by geologists. These dealt with the Age of the Earth. For centuries untold the entire age of the earth had been supposed to be only a few thousand years. When, however, Lyell predicated 100,000 years for the period of Man alone, when all the paleontologists demanded periods of millions of years for the gradual development of species, and when the astronomers and physicists demanded tens of millions of years for an explanation of earth conditions as their investigations showed them to be, it became evident that there was urgent need for a revision of the estimates of the age of the earth.

The first modern attempt to solve this problem was made by John Phillips, who, in 1860, introduced the use of various geological processes as vast time clocks. Among these methods the most general has been that of finding the time required to deposit a certain depth of material under certain conditions (such as the deposition of ooze on the sea-floor), then to calculate the thickness of the rocks of the earth's crust, and, by multiplying one by the other, to arrive at the length of time needed to lay down the sedimentary rocks. Such a system of calculation, however, can only be vaguely approximate, for, in the first place, the rate of deposit differs very widely, and in the second place, there is no means of determining the speed of deposition during the earlier periods of the earth's history. In addition to this, pressure on rocks causes a shrinkage. As the pressure is not the same at any two places, and as the variability of shrinkage in rocks is high, there is a further number of uncertainties added to the problem.

Professor Joly of Dublin, in 1881, gave figures for the Age of the Earth, based on the saltness of the sea, which, of course, is becoming steadily salter. There are about 12 quadrillion tons of common salt in the sea and 156 million tons are added every year. This estimate makes the ocean 77 million years old. But there are only about 454 trillion tons of potassium (which, like the salt, has been dissolved from the rocks) and 37 million tons are added annually. This would make the ocean only 12 million years old. The potassium, however, is taken up with iron in the making of glauconite, but the amount thus consumed is not enough to explain the difference between 12 and 17 million years. Besides all which, it is a pure assumption that the primeval ocean was free of dissolved materials. Still, by this method, Professor Joly gave a tentative estimate of the age of the oceans at 100 million years, and in the latest work along this line, Dr. A. R. Holmes in 1913 concluded that the limits would be between 210 and 340 million years.

The newer estimates of the age of the earth deal neither with sedimentation nor the saltness of the sea, but with questions of radioactivity. This discussion is connected historically with the estimates made by the astronomers and physicists, notably Lord Kelvin, who first in 1876 and again in 1897, calculated the earth's age from the fuel consumption of the sun and the internal temperatures of the earth. His revised figures were from 20 million to 40 million years for the whole of the earth's existence. Huxley promptly and bluntly denied this, declaring that "mathematics was not a proof, but a process; it was a mill that ground nothing but what was put into it."

Professor Perry, in 1903, nullified Lord Kelvin's figures by showing that the great physicist had made an unwarranted assumption in supposing that the materials in the interior of the earth conducted heat at exactly the same speed as the rocks in the crust. A little later, in connection with Professor Moulton's work, it was shown that the interior material conducts heat at least four times as quickly.

All this line of argument, however, passed into an entirely new phase with the discovery of radium and of radio-active rocks. The amount of radio-active rock, its rate of disintegration, the amount of heat emitted by the process—all these are new factors. In spite of the difficulties, Professor Strutt, in 1909, by a combined estimate from the amount of helium in fragments of phosphate and fossil bones and by tests of minerals such as iron ores and zircons, deduced the earth's age as approximately four billion years. It is still a disputed point, but the balance of authorities may be said to confirm the estimate of one billion years since the primitive rocks were first laid down.

Without a doubt the most important geological advance made during the past two centuries was the formulation of the new theory of the balance of the different areas of the earth's crust. This is known as isostasy, and was put forth by Professor Dutton in 1889. In 1909 Hayford, of the U. S. Geodetic Survey, closed a very complete investigation of isostatic conditions in the United States, and concluded that "The United States is not maintained in its position above sea-level by the rigidity of the earth, but is, in the main, buoyed up, floated, because it is composed of material of deficient density." The theory has the endorsement of Professor T. C. Chamberlin, one of the most eminent names in American geology.

This conception of the earth as a rigid crust floating on a fluidable foundation, however, appears to have been confronted by another problem. If the foundations are fluid, why do not the mountains sink into this fluid interior and thus bring the face of the earth to a uniform level? Dutton suggested, and modern science has supported his view, that the reason for the comparative heights and depths of mountains and ocean beds is due to the relative density of the rocks which compose them. Thus the rock masses of the Himalayas are far lighter than the rocks under the Indian Ocean, so much lighter, in fact, that their 25,000 extra feet of height do not cause the mass to be heavier than the weight of the ocean and the rock under the ocean floor, when both are measured through the outer crust to fluidable interior, nearly a hundred miles below.

Dr. Hecker, in 1911, by very careful experiments on the ocean floor, showed that the rocks were actually more dense, as the theory required. Hayford, Barrell and others in America showed that isostasy holds true for the whole continent except a few areas here and there, none of them larger than a county. The compensation is not exact, for the crust has considerable rigidity; but it is very close. With the advance in radio-activity and the growing authoritative support of isostasy, Geology in the Twentieth Century has advanced with tremendous strides.

CHAPTER VI

COMPOSITION OF THE EARTH

A DISCUSSION of the geological changes which this planet has undergone ought to be preceded by a study of the materials which enter into its composition. This branch of geology is technically termed Geognosy. The earth may be considered as a globe, which was cooled sufficiently to have a solid crust, enclosed in two envelopes or shells, the inner one of water covering about three-fourths of the globe and the outer one of gas completely enveloping the whole. This outer envelope of gas is known as the atmosphere, the water is called the hydrosphere, and the solid globe is the lithosphere or rock sphere.

There is every reason to believe that the present gaseous and liquid envelopes of the planet are only a portion of the original mass of gas and water with which the globe was invested. As Sir Archibald Geikie says in his "Text Book of Geology," "Fully a half of the outer shell or crust of the earth consists of oxygen, which probably once existed in the primeval atmosphere. The extent, likewise, to which water has been abstracted by minerals is almost incredible. It has been estimated that already one-third of the whole mass of the ocean has been thus absorbed. Eventually the condition of the planet will probably resemble that of the moon—a globe without air, or water, or life of any kind.

"The gaseous envelope to which the name of atmosphere is given extends from the earth's surface to a distance which has been variously estimated, according to the methods of observation employed. From the phenomena of twilight it may be inferred that the atmosphere must be at least 45 miles thick. The aurora indicates a sensible atmosphere at 100 miles, and clouds have been detected at heights of nearly 100 miles. Meteorites, which become incandescent by friction against our atmosphere, sometimes appear at heights of 150 miles. We may therefore infer that the atmosphere stretches for at least that distance from the earth's surface, and probably in a state of extreme tenuity much farther. At sea-level the mean pressure of the atmosphere is about 14¾ pounds per square inch."

Many speculations have been made regarding the chemical composition of the atmosphere during former geological periods. There can indeed be no doubt that it must originally have differed very greatly from its present condition. It has been contended, for instance, that originally there was little or no free oxygen in the atmosphere, which may have consisted mainly of nitrogen, carbonic acid, and aqueous vapor. Besides the abstraction of the oxygen which now forms fully a half of the outer crust of the earth, the vast beds of coal found all over the world, in geological formations of many different ages, doubtless represent so much carbon-dioxide (carbonic acid) once present in the air.

As now existing, the atmosphere is considered to be normally a mechanical mixture of nearly 4 volumes of nitrogen and 1 of oxygen (N79.4, O20.6), with minute proportions of carbon-dioxide and water-vapor and still smaller quantities of ammonia and the powerful oxidizing agent, ozone. These quantities are liable to some variation according to locality. The mean proportion of carbon-dioxide is about 3.5 parts in every 10,000 of air.

The other substances in the air are gases, vapors and solid particles. Of these, by much the most important is the vapor of water, which is always present, but in very variable amount according to temperature. It is by this vapor, together with the carbon-dioxide and suspended dust particles, that the radiant heat in the atmosphere is absorbed. The water-vapor condenses into dew, rain, hail, and snow, and is thus of paramount importance in the great series of surface agencies which play so large a part in the geological changes of the earth. In analyzing the air carried down in solution in rain water, the atmospheric gases, together with ammonia, nitric, sulphurous and sulphuric acids, chlorides, various salts, solid carbon, inorganic dust, and organic matter, have been detected.

The fine microscopic dust so abundant in the air is no doubt for the most part due to the action of wind in lifting up the finer particles of disintegrated rock on the surface of the land. As a geological agent, the atmosphere effects changes by the chemical reactions of its constituent gases and vapors, by its varying temperature, and by its motions.

Rather less than three-fourths of the surface of the globe (or about 144,712,000 square miles) are covered by the irregular sheet of water known as the Sea. Within the last few decades much new light has been thrown upon the depths, temperatures, and biological conditions of the ocean-basins, more particularly by the Lightning, Porcupine, Challenger, Tuscarora, Blake, Gazelle, and other expeditions fitted out by the British, American, German, Norwegian and Swedish Goverments. The water of the ocean is distinguished from ordinary terrestrial waters by a higher specific gravity, and the presence of so large a proportion of saline ingredients as to impart a strongly salt taste. The average density of sea-water is about 1.026, but it varies slightly in different parts even of the same ocean.

The greater density of sea-water depends, of course, upon the salts which it contains in solution. At an early period in the earth's history, the water now forming the ocean, together with the rivers, lakes, and snowfields of the land, existed as vapor, in which were mingled many other gases and vapors, the whole forming a vast atmosphere surrounding the still intensely hot globe. Under the enormous pressure of the primeval atmosphere, the first condensed water might have had a temperature little below the critical one. In condensing, it would carry down with it many substances in solution. The salts now present in sea-water are to be regarded as partially derived from the primeval constitution of the sea, and thus it may be inferred that the sea has always been more or less saline.

But it is manifest that, whatever may have been the original composition of the oceans, they have for a vast section of geological time been constantly receiving mineral matter in solution from the land. Every spring, brook, and river removes various salts from the rocks over which it moves, and these substances, thus dissolved, eventually find their way into the sea. Consequently, sea-water ought to contain more or less traceable proportions of every substance which the terrestrial waters can remove from the land—in short, of probably every element present in the outer shell of the globe, for there seems to be no constituent of the earth which may not, under certain circumstances, be held in solution in water.

The average proportion of saline constituents in the water of the great oceans far from land is about three and a half parts in every hundred of water; and the proportions of the different chemical elements in the composition of the waters of the ocean as a whole are much as follows: Oxygen, 85.79; hydrogen, 10.67; chlorine, 2.67; sodium, 1.14; magnesium, 0.14; calcium, 0.05; potassium, 0.04; sulphur, 0.09; bromine, 0.008; and carbon 0.002.

Within the atmospheric and oceanic envelopes lies the inner solid globe. The only portion of it which, rising above the sea, is visible to Man, and forms what is termed Land, occupies rather more than one-fourth of the total superficies of the globe, or about 52,745,000 square miles.

It was formerly the prevalent belief that the exterior and interior of the globe differ from each other to such an extent that, while the outer parts are cool and solid, the vastly more enormous inner intensely hot part is more or less completely liquid. Hence the term "crust" is applied to the external rind in the usual sense of that word. This crust was variously computed to be ten, fifteen, twenty, or more miles in thickness.

The earth's crust is composed of mineral matter in various aggregates included under the general term Rock. A rock may be defined as a mass of matter composed of one or more simple minerals, having usually a variable chemical composition, with no necessarily symmetrical external form, and ranging in cohesion from mere loose débris up to the most compact stone. Granite, lava, sandstone, limestone, gravel, sand, mud, soil, marl and peat, are all recognized in a geological sense as rocks.

Direct acquaintance with the chemical constitution of the globe must obviously be limited to that of the crust, tho by inference it may be possible eventually to reach highly probable conclusions regarding the constitution of the interior. Chemical research has discovered that some seventy-five simple or as yet undecomposable bodies, called elements, in various proportions and compounds, constitute the accessible part of the crust. Of these, however, the great majority are comparatively of rare occurrence. The crust is mainly built up of about twenty elements, which may be arranged in two groups, metalloids and metals. Of the metalloids, oxygen and silicon represent 75 per cent. of the matter in the world, hydrogen, carbon, phosphorus, sulphur, chlorine, fluorine and nitrogen being less than 1½ per cent. all together; while among the metals, aluminum is 7.45 per cent; iron, 4.2; calcium, 3.25; magnesium, 2.35; potassium, 2.35; sodium, 2.40, and titanium, manganese, barium, strontium, chromium, nickel and lithium together are less than one-half of one per cent. Of the other elements, upward of fifty in number, the proportions are so small that probably not one of them equals as much as one-hundredth of one per cent. of the whole crust. Yet they include gold, silver, copper, tin, lead and the other useful metals, iron excepted. It will be observed that of the accessible part of the globe over three-fourths consist of metalloids and less than one-fourth of metals. It is also interesting to note that 97 per cent. of the crust is made up of the 10 most abundant elements; that is, of the 3 first metalloids and the 7 first metals. Silicon is never found free, but always combined with oxygen.

Comparatively few of the elements occur free, but occur in more or less complex compounds with one or more others. The combinations which enter most largely into the composition of the earth's crust can best be determined from the collation of a sufficiently large number of chemical analyses of the more representative rocks of the earth's crust. Such a determination has been made by Mr. F. W. Clarke from the mean of 830 analysis of typical samples from the older or primitive part of the crust, and is expressed. The following are the chief: Silica (SiO_2) 59.71 per cent., alumina (Al_2O_3) 15.41, ferric oxide (Fe_2O_3) 2.63, ferrous oxide (FeO) 3.52, lime (CaO) 4.90, magnesia (MgO) 4.36, potash (K_2O) 2.80, soda (Na_2O) 3.55, water (H^2O) 1.52, titantic acid (TiO_2) 0.60, and phosphoric acid (P_2O_5) 0.22.

In a broad view of the arrangement of the chemical elements in the external crust, the speculation of Durocher may be noticed here.

He regarded all rocks as referable to two layers of magmas co-existing in the earth's crust, the one beneath the other, according to their specific gravities. The upper or outer shell, which he termed the acid or siliceous magma, contains an excess of silicia, and has a mean density of 2.65. The lower or inner shell, which he called the basic magma, has from six to eight times more of the earthy bases and iron-oxides, with a mean density of 2.96. To the former he assigned the early plutonic rocks, granite, felsite, etc., with the more recent trachytes; to the latter he relegated all the heavy lavas, basalts and diorites.

The rocks of the earth's crust are made up of compounds of the elements which have just been mentioned. These compounds geologists call minerals. Scott, in his "Introduction to Geology," defines a mineral as a natural, inorganic substance, which has a homogeneous structure, definite chemical composition and physical properties, and usually a definite crystal form. The number of known minerals is large, and constantly increasing, but only a few enter in any important way into the constitution of the earth's crust.

Having considered the composition of the atmosphere, sea, and solid crust, the general features of the earth's surface require attention. The late Professor Dana, of Yale, briefly summarizes the important physical features of the earth in his "Text Book of Geology," wherein he says: "The earth has a circumference of 24,899 miles. Its form is that of a sphere flattened at the poles, the equatorial diameter, 7,926 miles, being about 26⅔ miles greater than the polar diameter." About eight-elevenths of the earth's surface, or 144,000,000 square miles, is depressed below the rest, and occupied by the sea. This sunken part of the crust is called the oceanic basin, and the large areas of land are called the continents or continental plateaus. The area of the dry land is about 52,745,000 square miles.

"Nearly three-quarters of the land is situated in the northern hemisphere, and very nearly three-fifths of the oceanic basin in the southern hemisphere. The dry land may be said to be grouped about the North Pole, and to stretch southward in two masses, an Oriental, including Europe, Asia, Africa, and Australasia, and an Occidental, including North and South America. The ocean is gathered in a similar manner about the South Pole, and extends northward in two broad areas separating the Occident and Orient, namely, the Atlantic and Pacific Oceans, and also in a third, the Indian Ocean, separating the southern prolongations of the Orient, namely, Africa and Australasia. The Orient is made, by this arrangement, to have two southern prolongations, while the Occident, or America has but one. This double feature of the Orient accords with its great breadth; for it averages 6,000 miles from east to west, which is far more than twice the mean breadth of the Occident (2,200 miles). The inequality of the two continental masses has its parallel in the equality of the Pacific and Atlantic oceans; for the former (6,000 miles broad) is more than double the average breadth of the latter (2,800 miles). The northern portion of the Orient, or Europe and Asia combined, makes one continental area, Eurasia; its general course is east and west. The northern portion of the Occident, North America, is elongated from north to south."

The mean depth of the oceanic depression is about 14,000 feet; and the mean height of the land (according to Murray) 2,252 feet. The greatest depth reached by soundings (south of the Friendly Islands) is 30,930 feet; the greatest height on the land (Mt. Everest of the Himalayas) is 29,000 feet; hence the interval between the extremes of altitude and depression is over eleven miles. If the continental plateaus and the floor of the ocean were graded to a common level, the ocean would still have a depth of about 10,000 feet. The mean height of Europe is 939 feet; Asia, 3,189 feet; Africa, 2,021 feet; Australia, 805 feet; North America, 1,888 feet; South America, 2,078 feet. The mean depths of the great oceans are: of the North Atlantic, 15,000 feet; North Pacific, 16,000 feet; South Atlantic and South Pacific, and probably the Indian Ocean, about 13,000 feet.

The form of the ocean's bed has been fairly accurately determined. From north to south, along the middle of the Atlantic, there is a wide zigzag ridge or plateau, conforming nearly in trend to the American coast. It lies at a depth of 6,000 to 12,000 feet, while on either side the bottom slopes away to depths mostly between 15,000 and 20,000 feet. In the area of 4,000 fathoms and over, situated north of the island of Porto Rico, the United States Coast Survey steamer Blake found, in 1883, a depth of 27,366 feet. This greatest depth, and large areas of deep water, exist in the western part of the ocean. In the Pacific Ocean, a shallow area extends, with little interruption, from the Malay Archipelago southeastward beyond the Paumotu Islands, and thence northeastward to the Isthmus of Panama, southeastward to Patagonia, and southward to the Antarctic. The deepest parts of this ocean also are in its western half. One deep area is east of Japan; another, south of the Ladrones; others, near the Friendly Islands. Northward in the northern hemisphere the ocean shallows rapidly. The depth in Bering Strait is not over 150 feet; and between Great Britain and Iceland it does not exceed 6,000 feet, and is mostly under 3,000 feet.

The ocean's bottom has no steep ridges like those of ordinary mountain scenery. But broad elevations exist in some parts, as found in the soundings of the Tuscarora between the Hawaiian Islands and Japan. Besides these, there are many mountain ranges rising somewhat abruptly from the depths, having the islands of the ocean as their summits, which rival in length those of the continents. The Hawaiian range, if the coral islands in the line of the volcanic islands are included, has a length of 2,000 miles; and it rises steeply from depths of 15,000 to 18,000 feet. The mountains of Hawaii have a height above the ocean of nearly 14,000 feet, and a depth of 17,000 feet was found but 50 miles south of the island, thus making the whole height nearly 31,000 feet. The islands of the tropical Pacific make together an island chain about 5,000 miles long; and they are the tops of a mountain chain of this great length.

Along the oceanic borders, the sea is often, for a long distance out, quite shallow, because the continents continue on under water with a nearly level surface; then comes, usually at a depth of about 100 fathoms, or 600 feet, a rather sudden slope to the deep bed of the ocean. This is the case off the eastern coast of the United States, east and south of New England. Off New Jersey the deep water begins along a line about 80 miles from the shore; off Virginia this line is 50 to 60 miles at sea; and thus it gradually approaches the coast to the southward; while to the northward it continues 80 to 100 miles off from the New England coast, and passes far outside of Nova Scotia and Newfoundland. The slope of the bottom for the 80 miles off New Jersey is only 1 foot in 700 feet. The true boundary between the continental plateau and the oceanic depression is the commencement of the abrupt slope. The same abrupt slope near the 100-fathom line exists in the Gulf of Mexico. The British Islands are situated on a submerged portion of the European continent, and are essentially a part of that continent, the limit of the oceanic basin—the 100-fathom line—being 50 to 100 miles outside of Scotland and Ireland, and extending south around the Bay of Biscay. West of the English Channel the depth increases, in a distance of only ten miles, from 100 fathoms to 2,000. New Guinea in a similar way is proved to be a part of Australia. Such facts occur on most coasts; and they teach that the oceanic depression is generally separated from the continental plateaus by a well-defined outline.

The surface of the continent comprises plains or low-lands, plateaus or table-lands, and mountain ridges. The mountain ridges may rise either from the lowlands or the plateaus. The plateaus are large areas of approximately level surface at an altitude of a thousand feet or more above the sea. They are often parts of the great mountain chains, lying between the ridges, or forming the mountain mass out of which the ridges rise. For example, the regions of northern and southern New York are plateaus (the former averaging 1,500 feet in height, the latter 2,000 feet) situated on the western borders of the Appalachian chain; and the same is true of the Cumberland tableland in Tennessee. Between the Sierra Nevada and the Wasatch, there is a plateau of vast extent, called the Great Basin, having the Great Salt Lake in its northeastern portion; its height above the sea averages 4,000 feet; the Humboldt Mountains and other high ranges rise out of it. It continues northward into British America and southward into Mexico. The eastern part of New Mexico, with the western part of Texas, is a plateau of about the same elevation, called the Llano Estacado. The Desert of Gobi, between the Altai and the Kuen-Lun range, is a desert plateau about 4,000 feet high, while the plateau of Tibet, between Kuen-Lun range and the Himalayas, is 11,500 to 13,000 feet above the sea. Persia and Armenia constitute another plateau. These examples are sufficient to explain the use of the term.

The continents are constructed on a common model: they have high borders and a low center, and are, accordingly, basin-shaped. North America has the Appalachians on the eastern border, the Cordillera on the west, and between these the low Mississippi basin.

South America, in a similar manner, has the Andes on the west, the Brazilian Mountains on the east, and other heights along the north, with the low region of the Amazon and La Plata making up the larger part of the great interior. In the Orient there are mountains on the Pacific side, others on the Atlantic; and, again, the Himalayas, on the south, face the Indian Ocean, and the Altai Mountains face the Arctic seas. Between the Himalayas (or rather the Kuen-Lun Mountains, which are just north) and the Altai, lies the plateau of Gobi, which is low compared with the inclosing mountains; and farther west there are the lowlands of the Caspian and Aral, the Caspian lying even below the level of the ocean.

The Urals divide the 6,000 miles of breadth into two parts, and so give Europe some title to its designation as a separate continent. West of their meridian there are again extensive lowlands over middle and southern European Russia. In Africa there are mountains on the eastern border, and on the western border south of Guinea; there are also the Atlas Mountains along the Mediterranean, and the Kong Mountains along the Guinea coast; and the interior is relatively low, although mostly 1,000 to 2,000 feet in elevation. In Australia, also, there are highlands on the eastern and western borders, and the interior is low. All the continents are, therefore, constructed on the basin-like model.

There is a second great truth with regard to the continental reliefs: the highest border faces the largest ocean. Each of the continents sustains the truth announced. North America has its great mountains, the Cordillera, on the side of the great ocean, the Pacific; and its small mountains, the Appalachians, on the side of the small ocean. South America, also, has its highest border on the west. The Orient has high ranges of mountains on the east, or the Pacific side, and the lower ranges, as those of Norway and other parts of Europe, on the west; and the Himalayas face the great Indian Ocean, while the smaller Altai range faces the small Northern Ocean. In Africa, the mountains on the side of the Indian Ocean are higher than those on that of the Atlantic. In Australia the highest border is on the Pacific side; for the South Pacific fronting east Australia, is greater than the Indian Ocean fronting west Australia. Hence the basin-like shape before illustrated is that of a basin with one border much higher than the other; and with the highest border on the side of the largest ocean.

The features described have a vast influence in adapting the continents for Man. America has its highest border in the far west, with all its great plains and great rivers inclined toward the Atlantic; for through the Gulf of Mexico the whole interior, as well as the eastern border, has its natural outlet eastward. The Orient, instead of rising into Himalayas on the Atlantic border, has its great heights in the remote east; and its vast plains, even those of Central Asia, have their natural outlet westward, over Europe and through the Mediterranean, or toward the same Atlantic Ocean. Thus, as Professor Guyot has said, "the vast regions of the world, which are best fitted for man, by their climate and productions, are combined into one great arena for the progress of civilization."

CHAPTER VII

STRATA MOVEMENTS AND EARTHQUAKES

Dynamical Geology investigates the process of change at present in progress upon the earth, whereby modifications are made on the structure and composition of the crust, on the relations between the interior and the surface, as shown by volcanoes, earthquakes, and other terrestrial disturbances, on the distribution of land and sea, on the outlines of the land, on the form and depth of the sea-bottom, on marine currents, and on climate. Bringing together the whole range of geological activities, it leads to precise notions regarding their relations to each other, and the results which they achieve. In other words, the present order of things must be employed as a key by means of which to decipher the hieroglyphics of the past, and proceed from what may be directly observed to past changes which can only be inferred.

"We might assume," says Scott in his "Introduction to Geology," "that the present was so radically different from the far-distant past, that the one could throw no light upon the other. Such an assumption, however, would be most illogical, for there is nothing to support it. There is no reason to imagine that physical and chemical laws are different now from what they have always been, and the more we study the earth, the more clearly we perceive that its history is a continuous whole, determined by factors of the same sort as are now continuing to modify it." Some of these forces, however act with greater efficiency at the present time than they did in the past, others with less.

The dynamical agencies may, primarily, be divided into two classes: (1) the Subterranean Agencies, which act, or at least originate, at considerable depths within the earth; and (2) the Surface or Superficial Agencies, whose action takes place at or near the surface of the earth. The former are due to the inherent energy of the earth, and their seat is primarily subterranean, tho their effects are very frequently apparent at the surface. These agencies are also called "igneous" (from "ignis," fire), which is a misnomer; but the term is nevertheless in common use. The surface agents, including the circulation of the winds and waters, the changes of temperature, and the activities of living beings, all depend upon the sun's energy, and were that withdrawn, only such changes as are brought about by the earth's internal heat could continue in operation.

Some of the agencies that shall be considered may seem, at first sight, to be very trivial in their effects, but it must be remembered that they appear so only because of the short time during which they can be observed. For enormously long periods of time they have been steadily at work, and their cumulative effects must not be left out of account in estimating the forces which have made the earth what it now is.

No human eye has ever witnessed the birth of a mountain range, or has seen the beds of solid rock folded and crumpled like so many sheets of paper, or observed the processes by which a rock is changed in all its essential characteristics; "metamorphosed," as it is technically called. Yet these things are continually being accomplished in Nature's workshop. All such problems, however, must be discussed in connection with structural geology.

The logical order of treatment of these subjects is to begin with the subterranean agencies, because the most ancient rocks of the earth's crust were doubtless formed by these forces, and the circulation of matter upon and through the crust started originally from igneous rocks. These agencies fall naturally into two great groups: Diastrophism, or movements of the earth's crust; and Vulcanism, or the phenomena of volcanoes, geysers, etc.; while a third group, Earthquakes, is intimately associated with each of the others, but on account of its great importance will require separate treatment. Crustal movements to be discussed here may be distinguished as (1) Warping, which is a broad, gentle curving of the surface, upward or downward; (2) Direct Upheaval or Depression, with fracturing and dislocation of the rocks, which may be accompanied by a tilting of the strata. Diastrophic movements of this class are almost, if not quite, invariably associated with earthquakes and can be most conveniently studied in connection with the latter.

Permanent changes of level frequently accompany earthquakes, but these are sudden, and appear to be nearly always the result of dislocation or faulting. By change of level, in the general sense, is meant the gradual elevation or subsidence of land, with reference to the sea, over considerable areas. Such movements are very slow, and hence are apt to escape observation, so that there is much dispute as to the facts and still more as to their interpretation. But there is an abundance of indisputable evidence showing that considerable changes in level have been effected even since the dawn of civilization.

On certain coasts long inhabited by civilized man, ancient structures like quays and bridges, which were built in the water, may now be found high above it. Such changes have been noted in the Mediterranean lands, especially in southern Italy and the island of Crete. The so-called "Serapeum" at Pozzuoli, near Naples, is a famous and much discussed example of repeated oscillations upward and downward. This structure was built in Roman times, and probably began to sink while still in use, as appears from the two ancient pavements, one above the other. Three large monolithic columns of marble, about 40 feet high, are still standing erect, and on each of them is a belt about 10 feet above the ground and 9 feet wide, honeycombed by the boring mollusk, "Lithodomus," which still abounds in the neighboring bay, and many of the shells were actually found in the columns. Evidently, the building was once submerged to a depth of nearly 20 feet, and when under water the columns were attacked and perforated by the mollusk. Just when the reëlevation began is not definitely known, but it was probably completed in 1538, when a volcanic eruption in the neighborhood resulted in the formation of Monte Nuovo. For nearly a century past a slow movement of subsidence has been going on.

"Raised beaches," filled with the remains of marine animals, are a decisive proof of a rise of the land, or a fall in the sea, and evidence of a similar kind is given by raised coral reefs. The eastern coast of North America shows marks of relatively late elevation, increasing in amount northward. At the mouth of the Connecticut, the highest beach is 40 to 50 feet above sea-level, at Boston it is 75 to 100 feet, on the coast of Maine it is 200, and on that of Labrador 500 feet. On the eastern shore of Hudson's Bay the marine terraces and beaches extend up to 700 feet above sea-level.

In the geological period (Pleistocene) immediately preceding the recent one, several immense lakes existed in the interior of North America, some around the basins of the present Great Lakes, others in Utah and Nevada. The ancient shore-lines of these vanished lakes may still be seen, for the most part in admirable preservation; when first formed by the action of the waters, these beaches must have been level, but accurate surveys show that they are no longer so, but have undergone extensive warpings.

As ancient structures on long-inhabited coasts sometimes show elevation, they likewise sometimes show depression. On the north coast of Egypt ancient rock-cut tombs are now visible beneath the waters of the Mediterranean. South of Stockholm, in Sweden, the remains of an ancient hut were found in place, 65 feet below the surface, buried in marine deposits which contain shells of the same species now living in the Baltic. On the west coast of Greenland the sinking is so rapid as to have attracted the attention of the natives.

The sea-bottom south of Long Island must once have been dry land, because a river flowing into the sea cannot excavate the sea-bottom below the level of its mouth. The ancient channel of the Hudson has been traced by soundings out to the edge of the continental platform, more than 100 miles southeast of Sandy Hook. In the same manner the channel of the St. Lawrence may be followed out through the Straits of Belle Isle, and that of the Congo extends out 70 miles from the west coast of Africa, with a depth of nearly 1,000 fathoms.

What are known as earthquakes are caused by rapid vibrations of the earth's crust due to some sudden shock in the earth's interior. The displacements—that is, the amplitude of the vibrations—in the great majority of earthquakes is only a fraction of a millimeter. When it exceeds four or five millimeters the quake is destructive. The greatest destruction is wrought in instances where the buildings are built upon loose foundations or upon "made ground." Steel-framed structures founded upon bed rock do not fall easily, for they vibrate with the rock. Centuries ago the Chinese devised an instrument that detected these vibrations of the earth's crust, for the majority of them can only be detected by instruments. Their device, as have all successful subsequent ones, depended on the inertia of a suspended weight or pendulum. The delicately poised weight alone is unaffected by the vibrations; a paper under it moves with the tremblings of the crust, and a pen held by the pendulum records the movement. In the Chinese device their pendulum merely displaced little bullets which were carefully supported.

Modern instruments, called seismographs, do not only tell when an earthquake has occurred, but they record the tremors, different pendulums recording the various components, horizontal and vertical, of the movements. In the cases of a violent disturbance communication of all kinds is often cut off, but there are now seismographs in all parts of the world, and by comparing the times at which various instruments recorded similar phases of the shock the center of the disturbance can generally be accurately determined.

The study of seismographic records has brought to light many highly significant facts, among others that minute and insensible "tremors" of the earth are almost incessant, but some, at least, of these tremors are due to atmospheric changes, and it is not known how large a proportion of them are of subterranean origin. Another very important result of the seismographic observations is that when a very distant earthquake is registered, three series of waves are indicated, viz., the 1st and 2d phases of the preliminary tremors, and the larger waves of the main shock. Those first to arrive, called the preliminary tremors, are believed to be transmitted through the mass of earth along the chord of the arc included between the point of origin and the point of observation. The waves of the third series are longer and slower—*i.e.*, of greater amplitude and period—and constitute the "main shock"; they are believed to follow the curvature of the earth.

Sensible earthquakes are numerous, not less than 30,000 being the estimated number per annum; of course, the great majority of these are very light. It would be just to say that the crust quivers constantly. While any part of the earth's surface may be visited by earthquakes, there is a very great difference between different regions in regard to their seismicity—*i.e.,* the frequency and violence of the shocks which affect them. The main seismic regions, when plotted upon a map, are found to be arranged in two great-circle belts, one of which encloses the Pacific Ocean and the other girdles the whole earth. The latter includes the Mediterranean region, the Azores, the bed of the Atlantic westward from the Azores to the West Indies, those islands themselves, Central America, Hawaii, Japan, China, India, Afghanistan, Persia, and Asia Minor.

Although earthquakes are commonly perceptible upon the land, the most frequent seats of disturbance are in the bed of the sea. In the sea there are regions quite free from quakes and others of a high degree of seismicity, but quakes also occur in an isolated and scattered manner. Submarine cables are frequently interrupted at the same points. Thus the cables from the Lipari Islands to Sicily has been broken five times at the same point.

A great earthquake usually begins suddenly and without warning. A rumbling sound, quickly becoming a loud roar, accompanies or slightly precedes the movement of the ground, which is at first a trembling, then a shaking, and finally a rapid swaying, wriggling motion, describing a figure 8, which is extremely destructive and overthrows the buildings affected, and even in the open country it is impossible to keep one's feet. The surface of the ground has been repeatedly observed to rise in low, very swiftly moving waves, somewhat like those on the surface of water, upon the crests of which the soil opens in cracks, closing again in the wave-troughs. When the earth-waves traverse a forested region, the trees sway violently from side to side, like a field of ripe grain in the breezes. In the details of movement earthquakes differ greatly from one another; sudden and extremely violent vertical shocks may come from below, or the surface may writhe and twist in every direction, instead of rolling in waves; there may be only a single shock, or many successive ones.

Strictly speaking, the geological effects of earthquakes are of less importance than is usually supposed. The violent shaking of the surface often brings about great land-slips in mountain regions, which precipitate enormous masses of earth and rock from the heights down into the valleys. In all of the more violent quakes cracks and fissures of the ground are formed, which may close again or remain open, and may show a lineal, curved, zigzag, or radiating arrangement. Through these fissures great quantities of water and sand are often forced up from below and form little sand craters, or water-filled funnels on the surface. Frequently the fissures assume the character of "faults," or dislocations, one side being raised, the other depressed, so that long "scarps," or low cliffs, are left standing. In the San Francisco earthquake of 1906 two long lines of parallel faults were formed, with varying throw up to twenty feet.

A very common result of earthquakes is a change in the circulation of underground waters. Wells and springs go dry, while other springs are formed in new places, or old ones may be increased in volume. The changes in the form of the land surface produce corresponding changes in surface drainage; rivers are diverted into new channels or dammed into lakes, while streams intersected by fault-scarps form new cascades.

The great earthquake which occurred at the extremity of the Italian peninsula near Messina, in 1908, was at first seismologically explained as the propagated effect of a fault-slip. It was not the eruptive outburst of Etna, according to Sir Norman Lockyer, that set the earth quivering, but a prolonged tension of the crust, a sudden snap, an abrupt settlement, and then the waves of the quake. The celebrated geologist, Professor Edward Suess, of Vienna, expressed himself very pessimistically regarding the outlook. According to his theory, the constant Calabrian and Sicilian shocks do not result from volcanic outbeaks anywhere, but are occasioned by a "general sinking." A series of shocks which culminated in May, 1914, showed the general seismic unrest of the district.

In studying the causes of earthquakes in general, they are usually divided into two classes, "volcanic" and "tectonic," tho it is often impossible to determine to which of the two classes a given earthquake should be referred. The volcanic earthquakes, which are closely associated in time and space with volcanic eruptions, are due to steam explosions and to the struggles of the rising lava within the earth to escape. Tectonic earthquakes are held to be due to stresses in the interior of the earth, which, when suddenly yielded to by the rocks, cause the jar and shock which generates the earthquake. No entirely satisfactory hypothesis has been advanced to account for the origin of the stresses referred to above. The explanation usually accepted is that the earth is slowly contracting on account of the loss of heat, and that the crust, which must follow the shrinking interior, is being crowded into a smaller space, with resultant ruptures and shocks. On the other hand, it is contended by some geologists that all earthquakes are essentially volcanic in origin. The stresses induced by the changing of the earth's axis also have been put forward as an explanation.

Dr. T. J. J. See, of the naval observatory on Mare Island, was the foremost of the authorities who declared that the Messina earthquake was caused by the explosive force of steam generated by the percolation of sea water to the molten or red hot rocks far below the earth's surface. He asserted that the so-called waves following great earthquakes are not really "tidal." He affirmed that they are produced by seismic disturbances of the sea bottom, and should be called "seismic sea waves."

A seismic wave, explained Dr. See, is due to a sinking of the sea bottom at some distance from the shore. When this happens, the water flows in from all sides to fill in the depression. Then, when the currents meet at the center and raise a ridge by their mutual impact, the ridge collapses under gravity and sends the first great wave ashore. "Where the ridge of water once was," he wrote, "a second depression in the sea-level is thus developed; the water again flows as in the first case, and the process keeps on repeating itself.

"On June 15, 1896, the northern shores of Japan were visited by terrible earthquake shocks, which were recorded on seismographs in Europe. The disturbance originated beneath the Tuscarora Deep. This oceanic abyss, which reaches a depth of forty-six hundred fathoms, or more than twenty-seven thousand feet, is known as the worst earthquake region in the world. On the Japanese coast, as on that of South America, the water first withdrew from the shore, and later returned in a great wave. Along a region seventy miles in length the coast villages were washed away, and 30,000 people perished from the earthquake and the inundation.

"In other instances the water rises suddenly, overflows the coast, and washes ships inland, without any previous withdrawal from the shore. For instance, on December 29, 1854, the city of Simoda, in Japan, was overwhelmed by a sudden inrush of the sea about an hour after a violent earthquake. Seismic waves of this class are produced by an upheaval of the sea bottom, which lifts the overlying water bodily upward, causing it to rush in upon the shore."

In summing up, Dr. See said that "the so-called 'tidal waves' that follow violent earthquake shocks are due either to the sinking or to the elevation of the sea bottom, and that earthquakes themselves are due to the secular leakage of the ocean bottoms."

The great depth and the enormous pressure of the sea water, with the aid of capillary forces, drive it through the rock crust of the earth till it comes to the intensely hot strata some twenty miles below the surface. The earth in many places is at a high temperature inside, and steam develops under the crust. When the pressure of the steam accumulates, it finally shakes the solid crust until it gets relief through some opening.

Practical people, notably insurance companies, are asking the scientists whether seismic disturbances have not a common and determinable origin and if their cause can be ascertained if they will ever be able to foretell their occurrence. It has been noted that some thirty thousand shocks are detected annually by the recording instruments. Of all these only sixty are "world-shaking" and observable from a distance. The two rings which the earthquake districts make when plotted on the globe also have been referred to. Professor Milne and others attach peculiar significance to this geographical distribution.

Now, this is not merely a convenient geographical summary, but a physical fact of vital importance, according to recent researches by Professor Jeans. In a remarkable paper read before the Royal Society he gave reasons for believing that the earth is not so absolutely a sphere or spheroid, but is slightly of pear-shape. Under gravitational stress it is continually approaching the spheroidal form—the pear is being crushed into a sphere by its own attraction; and the result is a series of earthquakes which will naturally occur in the weakest places.

In 1912 Professor Davison pointed out that the tectonic strains are intermittent and that it is a misinterpretation of the seismological facts to try to force them to fit any one theory. He declared that probably all the factors known were operating together, many of them neutralizing, and that the cause of the sudden slip came with the arrival of a point of accumulated stresses when the frictional resistance and inertia of rock masses was overcome.

For many years it has been observed that there are slight but irregular changes in latitude, or, in other words, the axis of the earth does not always point in the same direction. The world top is not spinning truly, but it wobbles slightly. When the change in direction of its axis is sharp, large earthquakes have been frequent. If a swiftly moving body is, so to speak, compelled to turn a corner, that it should be subjected to strains which might result in yielding, is easily conceivable.

A shifting of the earth's axis, even to the slightest degree, would impose a great strain upon some parts of the earth's crusts, and this might explain earthquakes and in turn lead to appreciable results in foretelling them, but, to use the words of Professor Simon Newcomb, "earthquakes are due to shifting of the earth's strata, but what causes that shifting is not positively known." The general theory hitherto has been that the shifting is due to the gradual lessening of the earth's surface. The great prestige of Sir Norman Lockyer's name has been given to the Milne theory—that is, that the earthquake is a natural phenomenon resulting from the failure of the earth to swing true upon its axis.

The great seismic disturbances of the past few years tend, this expert thinks, to support the theory advanced by Professor Milne. This would yield the inference that it is possible to calculate the frequency of earthquakes in the light of their suspected cause. "However much announcements of this nature may appeal to the scientific mind," says Professor Milne, "the layman requires something more definite—if not to the minute he would at least like to know the day on which an earthquake is to occur."

The science of seismology may never become so precise as all that, but when the factor of causation is given, when it is known for certain whether or not the sun spots or the shrinkage of the globe or the alteration of the direction of the earth's axis must be given credit for the earthquake, the chief problem of the seismological prophet will have been practically solved.

CHAPTER VIII

VOLCANOES AND GEYSERS

A VOLCANO is usually a conical mountain or hill, with an opening, or crater, through which various solid, molten, or gaseous materials are ejected. The essential part of the volcano is the opening, or vent, and some volcanoes consist of almost nothing else. It is known that at least a part of the interior of the earth at a certain depth is hot and that a great part of it is actually or potentially molten. Thus a volcano might be considered as a connection between the interior and the surface, or as a chimney over an especially active part of the interior.

The number of volcanoes now active may be estimated at about 328, of which rather more than one-third are situated in the continents and the remainder on islands. The active volcanoes are not scattered haphazard over the surface of the globe, but are arranged in belts or lines, which bear a definite relation to the great topographical features of the earth as well as to the seismic belts. Two of these belts together encircle the Pacific Ocean. A third band occupies a ridge in the eastern bed of the Atlantic, from Iceland to beyond St. Helena, from which arise numerous volcanic islands and submarine vents.

The phenomena displayed by different volcanoes, or even by the same volcano at different times, vary greatly. It often seems difficult to believe that similar forces are involved, and that the divergences are due merely to different circumstances attending the outbreak. A careful comparison, however, of the varying phenomena brings to light a fundamental likeness in them all. Some vents, like Stromboli in the Mediterranean, are in an almost continual state of eruption of a quiet kind; others, like Vesuvius, have long periods of dormancy, broken by eruptions of terrible violence.

The first recorded eruption of Vesuvius, which occurred in 79 A.D. and is described in two letters written to Tacitus by the younger Pliny, was of the explosive type. In this frightful paroxysm little or no molten lava was ejected, but so enormous was the quantity of ashes that at Misenum, across the bay of Naples, the sun was darkened, as Pliny reports, "not as on a moonless, cloudy night, but as when the light is extinguished in a closed room. . . . In order not to be covered by the falling ashes and crushed by their weight, it was necessary to rise often and shake them off."

The explosive type of eruption is exhibited in its extreme form by several of the East Indian volcanoes, and preëminently by Krakatoa, the eruption of which in 1883 was the most frightful ever recorded. This volcanic island, situated in the Strait of Sunda, was little known, except that it had been in eruption in 1680. The catastrophe occurred in August, when, besides the fearful devastation caused by the disturbances of the sea on the coasts of Sumatra and Java, the island itself was almost annihilated.

The force of the explosion produced waves in the atmosphere which were propagated around the whole earth, and the first one was observed in Berlin ten hours after the explosion. The ejected materials were all fragmentary and of an incredible volume; ashes were distributed over an area of 300,000 square miles, the greater part falling within a radius of eight miles around the island; stretches of water that had had an average depth of 117 feet were so filled up as to be no longer navigable. Enormous masses of pumice floated upon the sea and stopped navigation except for powerful steamers. The flaming-red sunsets which characterized the autumn and winter of 1883-1884 have been very generally ascribed to the refractive effects of the impalpably fine Krakatoa dust.

The islands of St. Vincent and Martinique in the Lesser Antilles were devastated by a series of fearful and nearly simultaneous eruptions, which in certain important respects differ from those of any other known volcanoes. The volcano of St. Vincent, known as La Soufrière, began breaking out on May 6, 1902, in a series of tremendous steam explosions; May 7 the eruption became continuous and on the same day occurred the dreadful, descending "hot blast," a cloud of superheated steam and other gases, mingled with red-hot particles of ash, which rushed down the mountain and destroyed 1,400 human lives. The eruptions, which were repeated at varying intervals and with different degrees of violence for considerably more than a year, were characterized by the absence of lava and by the vast quantity of finely divided ash ejected by the explosions.

The eruptions of Mont Pelée in Martinique were actually less violent, but far more destructive to life than those of St. Vincent. On May 2 the ejections of ash became frequent, increasing until the 8th, when a descending cloud of hot vapors and glowing ash swept with terrible velocity down the ravine of the Rivière Blanche upon the city of St. Pierre, which, together with its 30,000 inhabitants, was instantly annihilated. The velocity of the air set in motion by the descending cloud was sufficiently great to hurl from its pedestal the great iron statue of Notre Dame de la Garde, weighing several tons, to a distance of more than 40 feet.

It is the descending clouds which lend such an exceptional character to the eruptions of St. Vincent and Martinique, but Mont Pelée also displayed certain other peculiar phenomena. While no lava streams were produced, very stiff and viscous lava appeared at the summit, filling up the old crater and forming a steep cone, through which protruded a lofty obelisk or spine, which, thrust up from below, grew irregularly in height, as it continually lost material by scaling off the top and sides; eventually it fell altogether.

In all eruptions of the explosive kind, a few typical examples of which are described above, the active agency is obviously exploding masses of intensely heated and compressed steam, and all such eruptions are accompanied by gigantic steam-clouds, which, condensing in the atmosphere, fall in rains of torrential volume and violence. The hot water thus produced mingles with the volcanic ash in the air and on the ground, forming streams of hot mud, which are often more destructive than the lava flows themselves. When cold, the mud sets into quite a firm rock, called "tuff."

The opposite extreme of volcanic activity from the explosive type is to be found in the volcanoes of the Sandwich Islands, such as Mauna Loa and Kilauea. Here the eruptions are usually not heralded by earthquakes; the lava is remarkably fluid and simply wells up over the sides of the crater, pouring down the sides of the mountain in streams which flow for many miles. More commonly the walls of the crater are unable to withstand the enormous pressure of the lava column, and the molten mass breaks through at some level below the crater, rising through the fissure in giant fountains, sometimes 1,000 feet high. Even in the ordinary activity of Kilauea jets of 30 and 40 feet in height are thrown up. Hardly any ashes or other fragmental products are formed; and tho the clouds of steam, the invariable accompaniments of volcanic outbursts, are present, yet the quantity of steam is relatively less than in those volcanoes in which explosions occur.

Between such extremes as the Hawaiian volcanoes on the one hand and the explosive East Indian type (Krakatoa) on the other may be found every intermediate gradation. Thus, tho occasionally breaking out with violence, Stromboli has been in a state of almost continuous activity for more than 2,000 years, and is, for long periods, in such exact equilibrium, that barometric changes have a marked effect upon its activity and the Mediterranean sailors make use of it as a weather signal.

Evidently one active agent in these phenomena is imprisoned steam in its struggles to escape. Different as are the manifestations at various volcanoes, steam is an important cause of the eruption in all cases, tho the conditions under which it acts vary widely.

In the modern eruptions of Vesuvius essentially the same phenomena may be observed, but on a far grander and more terrible scale. Earthquakes usually announce the coming eruption, increasing in force until the outbreak occurs. Terrific explosions blow out fragments of all sizes, from great blocks to the finest and most impalpable dust. Inconceivable quantities of steam are given off with a loud roar, which is awe-inspiring in its great and steady volume.

A volcano, as its activity wanes, may pass into the Solfataric stage, when only volatile emanations are discharged. The well-known Solfatara near Naples, since its last eruption in 1198, has constantly discharged steam and sulphurous vapors. The island of Vulcano has now passed also into this phase, tho giving vent to occasional explosions. As the result of solfataric action, masses of rock are decomposed below the surface and new deposits of alum, sulphur, sulphides of iron and copper, and layers of silica, etc., are formed above them. The "lagoons" of Tuscany are basins into which the waters from soffioni are discharged, and where a precipitation of their dissolved salts takes place. Among the substances thus deposited are gypsum, sulphur, silica, and various alkaline salts; but the most important is boracic acid, the extraction of which constitutes a thriving industry.

Another class of gaseous emanations betokens a condition of volcanic activity further advanced toward final extinction. In these the gas is carbon-dioxide, either issuing directly from the rock or bubbling up with water which is often quite cold. The famous Valley of Death in Java contains one of the most remarkable gas-springs in the world. It is a deep, bosky hollow, from one small space on the bottom of which carbon-dioxide issues so copiously as to form the lower stratum of the atmosphere. Tigers, deer, and wild-boar, enticed by the shelter of the spot, descend and are speedily suffocated. Many skeletons, including those of man himself, have been observed. "Death Gulch" is the significant name given to another example of the accumulation of carbonic acid in Western America.

Eruptive fountains of hot water and steam, to which the general name of Geysers—*i.e.*, gushers—is given, from the examples in Iceland, which were the first to be seen and described, mark a declining phase of volcanic activity. Iceland has long been famous for its geysers, and a very beautiful series in New Zealand was destroyed by the volcanic eruption in 1886. But probably the most striking and numerous assemblage is that which has been brought to light in the "Yellowstone National Park." In this singular region the ground in certain tracts is honeycombed with passages which communicate with the surface by hundreds of openings, whence boiling water and steam are emitted. In most cases the water remains clear, tranquil, and of a deep green-blue tint, tho many of the otherwise quiet pools are marked by patches of rapid ebullition. These pools lie on mounds or sheets of sinter and are usually edged round with a raised rim of the same substance, often beautifully fretted and streaked with brilliant colors. The eruptive openings usually appear on small, low, conical elevations of sinter, from each of which one or more tubular projections rise. It is from these irregular tube-like excrescences that the eruptions take place. The term geyser is restricted to active openings whence columns of hot water and steam are from time to time ejected; the non-eruptive pools are only hot springs.

In the Upper Fire Hole basin of the Yellowstone Park one of the geysers, named "Old Faithful," ever since the discovery of the region has sent out a column of mingled water and steam every sixty-three minutes or thereabouts. The column rushes up with a loud roar to a height of more than 100 feet, the whole eruption not occupying more than about five or six minutes. The other geysers of the same district are more capricious in their movements, and some of them more stupendous in the volume of their discharge. The eruptions of the "Castle," "Giant," and "Beehive" vents are marvelously impressive.

The action of geysers is due to the condition that subterranean waters have access to hot rocks (as the interior of great lava sheets, retaining a high temperature on account of the poor conductivity of the material), and that the conduit communicating with the surface is so narrow that convection currents cannot be freely established. The heat accordingly increases in the deeper part of the column of water, until steam is formed, by whose expansion the cooler waters above are explosively ejected. After an eruption the water flows back into the underground passages and gradually becomes heated up for another explosion.

Heated waters act on the rocks with which they are in contact and decompose them, and, as most rocks—especially volcanic rocks—contain some kind of feldspar, the waters become slightly alkaline through the alkali of the feldspar, and so are enabled to take up silica and make siliceous solutions. The silica taken into solution is deposited again around the geyser in many beautiful forms and makes the bowl or crater from which the waters are thrown out.

From a geological point of view the products of volcanic action form a most important part of the subject, because they contribute largely to the permanent materials of the earth's crust. Volcanic products are of three kinds: (1) Lava, or molten rock; (2) fragmental material, including blocks, lapilli, bombs, the so-called volcanic ashes, cinders, and the like; (3) gases and vapors.

A lava is a more or less completely melted rock; the degree of fluidity varies greatly in different lavas, but is rarely if ever perfect. The degree of fluidity depends upon several factors, the most obvious of which is temperature; the more highly heated the mass is, the more perfectly will it be melted. The quantity of imprisoned gases and vapors present has also an important effect, and some lavas appear to owe nearly all their mobility to these vapors. A third and most significant factor is the chemical composition. Those lavas which contain high percentages of silica, the acid lavas, are much less readily fusible than the basic lavas, in which the percentage of silica is lower.

When a lava stream reaches the surface of the ground, the imprisoned vapors immediately begin to escape and the surface of the molten mass to cool and harden. The surface layers are blown by the steam bubbles into a light, frothy or slaggy consistency, forming "scoriæ" or cindery masses. The motion of the lava breaks up this thin crust into loose slabs and blocks, and on the advancing front of the stream these loose masses rattle down over one another in the wildest confusion. The front of a lava stream advances, not by gliding over the ground, but by rolling, the bottom being retarded by the friction of the ground and the top moving faster, so that it is continually rolling down at the curved front end and forming the bottom. Ordinarily the motion soon becomes very slow, tho thoroly melted masses pouring down steep slopes may, for a short time, move very swiftly. One of the lava floods from Mauna Loa moved fifteen miles in two hours, and for shorter distances much higher rates of speed have been observed; but this is very exceptional.

When lava cools rapidly, it solidifies as a glass—obsidian or tachylite. When it cools slowly, it forms a truly crystalline rock. Between the extremes are various gradations. If the swiftly cooling portions have been much disturbed by the bubbles of steam and vapors, they are made light and frothy; in some cases, as in pumice, they will float upon water. The lavas which contain large crystals embedded in a fine stony or glassy base are said to be of a "porphyritic texture." A mass of lava, when it cools and solidifies, necessarily contracts, and since the cohesion of the mass is insufficient to allow it to contract as a whole, it must crack into blocks, separated by fine crevices, which are called joints.

Not all the lava produced in and around a volcanic vent can reach the surface. Some of it may be forced horizontally between beds of the surrounding rocks, thus forming intrusive sheets, which, when exposed in sections, may be readily distinguished from surface flows by the fact that they have consolidated under pressure, and hence have no slag or scoriæ associated with them. Other portions of the lava will fill up vertical fissures in the volcanic cone or in the underlying rocks, and, solidifying in these fissures, form "dikes." Such a fissure, twelve miles in length and filled with molten lava, was observed by Sir Charles Lyell in the neighborhood of Etna.

The division of fragmental products includes all the materials which are ejected from the volcano in a solid state. These are of all sizes and shapes, from huge blocks weighing many tons, down to the most impalpable dust, which the wind will carry for thousands of miles. The more violently explosive the eruption, the greater the proportion of the lava that will be blown into fragments. In such eruptions as that of Krakatoa, all of it is thus dispersed and none remains to form lava flows. Cindery fragments thrown out of the vent are called "scoriæ," while portions of still liquid lava thus ejected will, on account of their rapid rotation, take on a spheroidal form and are called "volcanic bombs." "Lapilli" are smaller, rounded fragments, and "volcanic ash" and "dust" are very fine particles, tho with a wide range of variation in size. The term "ash" is so far unfortunate that it implies combustion, but nevertheless it accurately describes the appearance of these masses.

In the immediate neighborhood of the vent fragments of all sizes accumulate, but the farther from the volcano, the smaller do the fragments become. The coarser masses around the vent form a "volcanic agglomerate," in which the fragments are of all shapes and sizes, heaped together without any arrangement. More regular sheets of large angular fragments form "volcanic breccia," and these may be seen on a grand scale in the Yellowstone National Park and in many other parts of the Rocky Mountain region. The finer accumulations of ash, formed at a greater distance from the vent, are roughly sorted by the air and often quite distinctly divided into layers, while, as already explained, the muds on drying set into quite a firm rock, called "tuff" or "tufa."

It is important to emphasize the vast quantity of material which, in many volcanic eruptions, is brought from the interior of the earth and deposited on the surface. Thus the eruption of Skaptar Jokul in Iceland, in 1783, produced an amount of lava which is calculated as exceeding six cubic miles in volume. The fragmental materials derived from the great explosion of Krakatoa, in 1883, are estimated at 4.3 cubic miles, while for that of Temboro, in 1815, Verbeek gives the almost incredible figures of 28.6 cubic miles.

As the ejections flow off or fall more or less symmetrically around the vent, the form of a volcanic peak necessarily tends to become conical.

The cone of Vesuvius consists mostly of cinders, and is accordingly steep, nearly 40°. Etna, about 10,000 feet high, and Mauna Loa in Hawaii, nearly 14,000 feet, consisting of lava streams, have an average slope of less than 10°. A tufa cone is midway between these two extremes.

From the days when Werner and his followers declared volcanic action to be caused by subterranean beds of inflammable material taking fire, speculation has been constant as to the underlying reasons that promote the heat expressed by volcanoes. The contraction of the earth in consequence of its secular cooling was the conception that met with the greatest favor, especially since Cordier calculated that were the earth to contract one millimeter, or one-twenty-fifth of an inch, it would suffice to cause 500 eruptions, each ejecting 1,300,000,000 cubic yards of lava.

By common consent geologists have recognized that the source of volcanic energy must be sought in the high temperature of the interior of the globe. They agree that the main proximate cause of the ordinary phase of eruptivity marked by the copious evolution of steam and the abundant production of dust, slags and cinders from one or more local vents, is obviously the expansive force exerted by vapors dissolved in the molten magma from which lavas proceed. Whether and to what extent these vapors are parts of the aboriginal constitution of the earth's interior, or are derived by descent from the surface, is, however, a question on which opinions differ.

Professor Tschermak and others have been led to conclude that the gaseous ejections are essentially portions of the original constitution of the magma of the globe, and that to their escape the activity of volcanic vents is due.

On the other hand, since so large a proportion of the vapor of active volcanoes consists of steam, many geologists have urged that this steam has in great measure been supplied by the descent of water from above ground, as it percolates down cracks and joints and infiltrates through the very pores of the rocks.

It appears to be probable that, somewhat like the reservoirs in which hot water and steam accumulate under geysers, the subterranean magma receives a constant influx of water from the surface, which cannot escape by other channels, but is absorbed by the internal magma at an enormously high temperature and under vast pressure. In the course of time the materials filling up a volcanic chimney are unable to withstand the upward expansion of this imprisoned vapor or water-substance, so that, after some premonitory rumblings, the whole opposing mass is blown out and the vapor escapes in the well-known masses of cloud. Meanwhile the removal of the overlying column relieves the pressure on the lava underneath, saturated with vapors or superheated water. This lava therefore begins to rise in the funnel until it forces its way through some weak part of the cone or pours over the top of the crater.

An obvious objection to this explanation is the difficulty of conceiving that water should descend at all against the expansive force within. But Daubrée's experiments have shown that, owing to capillarity, water may permeate rocks against a high counter-pressure of steam on the further side, and that so long as the water is supplied, whether by minute fissures or through pores of the rocks, it may, under pressure of its own superincumbent column, make its way into highly heated regions.

The great physicist, Professor Arrhenius of Stockholm, has done much to clarify the views superincumbent upon modern investigation. Pointing out the amazing potency of force possessed by water-vapor at a temperature far above the critical point, he notes that the magma is charged with this and compares the explosive discharge of lava and viscous matter in volcanic vents to the ascent of water in a geyser.

At a depth of 540 meters the vapor in the magma must press upward through the molten mass in gas bubbles, and as it escapes the column of liquid is forced upward, sometimes even with explosive violence. At the end of the eruption all the water in the lava column must again be in equilibrium down to that depth, and if no other agency intervened the molten rock would gradually cool and stiffen, so that no further discharge would take place in that funnel. But observation shows that eruptions may continue constant at the same spot for centuries and, as at Stromboli, may be as frequent as those of geysers.

The gaseous water above the critical temperature, in consequence of the enormous pressure (1,000 atmospheres at 10,000 meters down) beneath the surface, may have the same density as liquid water, probably rather less, and will press into the magma. The investigations of recent years have shown, moreover, that superheated subterranean water possesses entirely different properties from those above ground. At about 300° it is estimated that water and silicic acid are about equally strong, but that at 1,000° water is some eighty times and at 2,000° about three hundred times stronger than that acid.

It is a common error to criticize the inability of geologists to explain these matters, and the inexpert reader is very apt to declare that all that is necessary to be known is the nature of the interior of the earth and all the phenomena of vulcanism will arrange themselves in due sequence. In this the casual observer is right, but he forgets that a cognition of the interior of the earth in the present state of scientific investigation is so far impossible. The deepest boring ever made is less than one-three-hundredth part of the earth's radius, and this was in the form of a hole a few inches in diameter.

To give an illustration which may show the cause of the little knowledge of the earth's interior. Suppose the smallest insect visible to the human eye to be resting on the surface of an orange, and suppose this tiny insect again to be possessed of a boring instrument like the mechanisms of Man, only of course comparable to its own size; that is to say, microscopic to the eye of Man. If this insect should force this tiny borer into the orange, it would not penetrate the outer orange-colored skin of the fruit, much less would it reach the white rind within, while the pulp beneath the rind would forever be distant from its mental grasp. If, however, some inner stress in the orange should cause a fissure, through which the juice within should ooze out, in what manner could the insect (supposing it possessed of equivalent mental powers with Man) explain the emission of the juice from its knowledge of the orange-colored cuticle of the fruit? In similar wise the geologist of to-day is in no position to declare the nature of the interior of the earth from the slight scratchings that have been made upon the surface of the earth by such means as mines, wells and so-called deep borings. He has not even reached the rind, much less the pulp within.

From observations with the pendulum and plumb-line it is calculated that the specific gravity of the earth as a whole is 5.6, while the average specific gravity of the rocks which form the accessible parts of the crust is only 2.6. It follows that the interior of the globe is composed of much denser materials than the superficial portion, and this fact, together with the phenomena of terrestrial magnetism, has led many to the belief that the earth is substantially a globe of some dense substance, such as iron.

Volcanoes, which eject molten and white-hot lavas, and thermal springs, which pour out floods of hot and even boiling water, indicate that the interior of the earth is highly heated, at least along certain lines. But this only reveals a stratum of intense heat and does not prove the heat of the entire interior.

It has long been known that after passing through a zone of variable temperature the heat increases with the depth below the surface. In New York the rate is 1° F. for every 50 feet and in Prussia, where the deepest borings have been made, it is 1° F. for every 60 feet of descent. Should this rate be continued regularly, it would reach, at a depth of 35 miles, a heat sufficient to melt almost any known rock at atmospheric pressure. Yet a depth of 35 miles in comparison with the diameter of the earth is almost a negligible quantity.

Opinions concerning the internal constitution of the earth differ very radically and only within the last few years has evidence begun to accumulate which permits the drawing of certain inferences with a considerable degree of probability. Many hypotheses as to the condition of the earth's interior have been proposed, of which the following are the most important: (1) That the earth is a molten globe, covered only by a relatively thin crust. (2) That it is substantially a solid body. (3) That the interior passes gradually from a solid crust to a gaseous core, heated beyond the critical temperature and yet under such enormous pressure that the core is as rigid as a solid body, but still a gas in molecular condition. According to this theory, the temperature of the earth at the center is about 180,000° F. and the pressure 3,000,000 atmospheres. (4) That it has a very large solid nucleus surrounded by a layer of fused material, upon which the crust floats in equilibrium.

William B. Scott deals with these hypotheses as follows:

"(1) The first, or 'thin crust' hypothesis, is now almost entirely abandoned, for there is really no evidence in its favor and very much against it. The velocity and character of the earthquake waves and the astronomical relations of the earth as a planet, especially the tidal phenomena, are strongly opposed to this view.

"(2) That the earth is substantially a solid body is the opinion held at present by many geologists and astronomers. In support of it may be cited the astronomical evidence just mentioned, and the earthquake waves, the speed of which requires a medium more rigid that steel, while the very transmission of the transverse or distortional waves would seem to require a solid medium.

"(3) Between the second and third hypotheses the distinction is one not easy to explain in an elementary manner, and there are many modifications of the latter. According to Arrhenius, 'the rigidity of the earth is greater rather than less than that of steel, but the interior forms an extremely viscous mass, with qualities somewhat like those of asphalt at a low temperature, of pitch, sealing-wax and glass.' These bodies behave under forces of deformation, which act quickly or with constantly changing direction, like solids; but under slow, long-continued pressures, acting in a constant direction, they behave like fluids. Observations and records of very distant earthquakes show that when the path of the mass-waves penetrates to a depth of more than three-fifths of the earth's radius, the transverse waves of distortion are either extinguished or greatly retarded. This points to a change in the character of the medium and decidedly supports the notion of a gaseous core postulated by this hypothesis.

"(4) The fourth hypothesis, which assumes the presence of a fused layer between the crust and the solid nucleus, with gradual transitions from one to the other, is believed to avoid the astronomical objections to a molten globe, as well as certain geological difficulties in accepting the hypothesis of an entirely solid earth. The earthquake observations, so frequently cited, are decidedly opposed to the belief that a layer of actually fused matter can exist at a moderate depth below the surface.

"It is thus probable that below the superficial crust, only a few miles in thickness, the great mass of the earth is composed of very dense material, which transmits elastic waves like a very perfectly elastic solid, and yet is so highly heated and under such enormous pressure that it is potentially fused and liquefies upon sufficient release of pressure, and yields plastically to slow, long-continued stresses which act in a constant direction. Furthermore, there is evidence that a core, two-fifths of the earth's diameter and composed of matter in a different state of aggregation, which may be gaseous, occupies the center."

In summing up volcanic activity, then, it may be said that a volcano is a pipe reaching far down into the ground, towards the fluidable stratum underneath the outer crust. The pressure of the overlying rocks prevents this fluidable rock becoming fluid; but if a fissure be opened—such as the vent of a volcano—the overheated fluidable rock will rise until the pressure is so reduced that it can become molten and discharged as lava.

If the fluidable rock is saturated with gas (as is usually the case) at the critical instant when the pressure is released, the gases explode and the lava is blown into fragments. The largest blocks fall near the volcano and are known as "agglomerate." Fragments from the size of a cocoanut to that of a peanut are known as "scoria" or "ash." The finer pieces—which may be held in suspension in the air for years—are known as volcanic "dust." The gorgeous sunsets of 1883, 1884, and 1885 were due to volcanic dust ejected by the great eruption of Krakatoa in 1883. The moisture discharged in an eruption may be carried several miles into the air. It is there condensed as rain and is precipitated through the dust-filled atmosphere, causing torrents of mud. Thus Pompeii was buried under volcanic scoria, and Herculaneum was choked and filled over by volcanic mud.

It is generally believed by geologists that volcanic activity is decreasing, but slowly. It is certain that it is periodic, but the length and character of the periods cannot be determined until a number of related problems, such as sunspots, the shifting of the earth on its axis, the extent and character of radio-activity, etc., have been determined.

CHAPTER IX

EROSIONS AND LANDSLIDES

All superficial agents are manifestations of solar energy, as indeed is circulating water which penetrates a certain distance below the surface. These are usually termed destructive and reconstructive processes, words which describe the work rather than define them. It can scarcely be said that the matter of the earth is destroyed or that it is reconstructed, but it may perhaps be said that it is destroyed as one form of rock and built up again as another. Thus, for example, a granite cliff, against which the sea dashes, will little by little be worn away. The particles thus worn away are sand, and this sand, under suitable pressure and heat, will become sandstone, a very different material from granite. Thus it is possible to say that the granite has been destroyed and the sandstone constructed, but it must not be forgotten that the particles of matter themselves have simply changed their order of arrangement. These two processes are complementary; for, since matter is indestructible, and can have only its position and physical and chemical relations changed, it is obvious that what is removed in one place must be laid down in another. In studying the work of the surface agents, the logical order of treatment requires that the destructive operations be considered first. The agencies to be examined are: (1) The atmosphere, (2) running water, (3) ice, (4) lakes, (5) the sea, (6) animals and plants. Of these various agents the work is principally mechanical, but water, in its various forms, is a slow but extremely efficient agent of chemical changes.

The atmospheric agencies are by far the most important of the destructive or denuding agents, because no part of the land surface is altogether exempt from their activity. Their work is described by the general term weathering and is shown at once by the different appearance of freshly quarried stone from that which has been long exposed in the face of a cliff, or even in ancient buildings. While such agents as rivers and the sea do work that is much more apparent and striking than that of the atmosphere, yet they are more locally confined, and even in their operations the atmosphere renders important aid.

There are, in the first place, the great differences of climate to be considered, differences in the amount and distribution of the rainfall, of temperature and of the winds, and, in the second place, the resistance offered by the various kinds of rocks to the disintegrating processes. The outcome of all these varying factors is to produce very irregular land surfaces. While the tendency of the atmospheric agencies is gradually to wear down the land to the level of the sea, yet in that process some parts are cut away much more rapidly than others, and hence the first effect of denudation is an increasingly irregular surface.

The atmospheric agents may be conveniently divided into (1) rain, (2) frost, (3) changes of temperature, (4) wind.

The work of the rain, which is both chemical and mechanical, varies greatly in accordance with climatic factors. Amount, frequency and violence of the precipitation, together with its temperature and regularity, all modify the effect. Perfectly pure water would act upon rocks with extreme slowness, but such water is not known to occur in nature. The raindrops, formed by the condensation of the watery vapor of the atmosphere, absorb certain gases, chiefly oxygen and carbon dioxide, which very materially increase the solvent power of the water.

One of the first and simplest effects of atmospheric moisture consists in the hydration of the minerals exposed to it. Hydration, the taking up of water into chemical union, is an important agency of decay, since it causes an increase of volume and thus greatly increases the pressure in the lower parts of rock masses, causing them to keep breaking into smaller and smaller blocks. Oxidation affects especially the iron minerals and thus brings about conspicuous color changes, for iron compounds form the principal coloring matter of the rocks and soils. An especially important and widespread change is carbonation, due to the carbon dioxide which all natural waters contain in greater or less quantity.

Finally, solution plays a highly important rôle in the destructive work of the rain. All rocks contain some soluble material, and when this soluble material is removed, the rock crumbles into a friable mass, which, on complete disintegration, forms soil. This may be illustrated by a block of frozen earth, which is as hard as many rocks, being cemented by the ice crystals, which bind the particles of soil together. When the ice is melted, the mass immediately becomes incoherent. So, in the rocks, the removal of even a small quantity of soluble material often causes the whole to crumble.

Most igneous rocks are made up of crystals of some kind of felspar, associated with such minerals as augite, hornblende and quartz. In granite, for example, rain-water slowly attacks the orthoclase by dissolving out the potash, probably as a carbonate, and also a considerable proportion of the combined silica, and the decomposition finally results in the formation of clay, through which are scattered flakes of mica (if mica were originally present) and the unaltered grains of quartz.

Rocks which are themselves composed of substances derived from the decay of older rocks are attacked in their turn and yield material for new formations. These derivative rocks, such as sandstones, slates and limestones, are affected in characteristic ways by the rain. In a sandstone with siliceous cement the action is excessively slow, atmospheric waters having very little effect upon silica, but underground it is slowly attacked. The uppermost layers of red sandstone are completely disintegrated into loose sand, bleached by the removal of the iron which gave it its color. In sandstones and slates it is the cementing substance which is removed, leaving the grains of sand or particles of clay unchanged, and with calcareous cement disintegration is rapid. Slates and shales, by removal of their soluble constituents, crumble down into clay.

Limestones, chiefly or entirely carbonate of lime, are attacked by rain-water, dissolved and carried away in solution, while the insoluble impurities contained in the rock remain to form soil. The gradual formation of soil by the disintegration of rock may be easily observed in excavations, even shallow ones, such as cellars, wells, railroad cuttings, and the like. At the surface is the true soil, which is usually dark-colored; next follows the subsoil, which, owing to the absence of vegetable matter and the less complete oxidation and hydration, is of a lighter color. By imperceptible gradations the subsoil shades into what looks like unaltered rock, but is friable and crumbles in the fingers; this is "rotten rock." From this to the firm, unchanged rock the passage is equally gradual.

The mechanical effect of rain is less extensive perhaps than its chemical work of disintegration, but is very important, nevertheless. Under ordinary conditions this mechanical work consists in the washing of the soil from higher to lower levels. How considerable is the movement of soil that has thus been brought about may be imagined when one sees, after a heavy rain, the rills which run over the slopes, muddy and charged with sediments, and how turbid the streams become with the soil which the rain washes into them. The mechanical action of rain is greatly increased by extreme violence and volume of precipitation; a single "cloud-burst" will do far more damage than the same quantity of rain falling in gentle showers.

One of the most remarkable monuments of rain erosion is exhibited by the curious districts in the far Western States known as the Bad Lands, which cover many thousands of square miles in the Dakotas, Nebraska, Wyoming, Utah, etc. The bad-land rocks are mostly rather soft sandstones and clays, with prevailingly calcareous cements, and formed in nearly horizontal beds or layers. The rainfall is light, tho torrential showers sometimes occur, but the absence of vegetation is favorable to its efficiency, and the present aridity of the climate is not of very long standing from a geological point of view. The chemical action of the rain has disintegrated the rocks by dissolving out the calcareous cement, and then the débris so formed has been mechanically washed away.

Differential weathering, or irregular disintegration, has resulted in that remarkable variety and grotesqueness of form resembling the ruins of gigantic towers and castles, for which the bad-land scenery is famous. The removal of the protecting vegetation is often speedily followed by disastrous results, and especially the reckless and wanton destruction of the forests, which has gone on in this country ever since its settlement by Europeans, has been followed by the loss of valuable soil on a vast scale.

The term frost, as a surface agent in dynamical geology, is restricted to the freezing of water. Water is one of the comparatively few substances which expand considerably on solidifying. This expansion amounts to about one-eleventh of the original bulk of the water, and, exerting a pressure of somewhat more than 2,000 pounds per square inch, takes place with irresistible power, bursting thick iron vessels like egg-shells. All rocks are divided into blocks by joints and are traversed by minute crevices, rifts and pores, all of which openings take up and retain quantities of water, as may readily be seen by examining freshly quarried stone.

The water freezes and forces out the large blocks and shatters them into pieces of smaller and smaller size. The fragments thus formed are called talus, and great accumulations of such blocks are formed at the foot of cliffs in all regions where the winters are at all severe. Alternate freezings and thawings not only break up rocks, but cause the broken fragments and soil to work their way down slopes. Each freezing causes the fragments to rise slightly at right angles to the inclined surface, and each thawing produces a reverse movement; hence the slow creep down the slope.

Immense accumulations of frost-made talus are to be found in such places as the foot of the Palisades of the Hudson and at Sherman, where the Union Pacific Railroad crosses the "continental divide," the ground is covered for miles with small, angular fragments of granite broken up by the frost.

Sudden changes of temperature form another of the processes by which rocks are broken. Their influence is greatest where the changes are most extreme, as in arid regions, especially high mountains and plateaus. The exposure of a naked rock to the burning rays of the sun, followed by the rapid radiation in thin air, causes extreme expansion and contraction. As, however, the heat has penetrated some distance into the interior of the rock and the surface cools first the cause is that of a cooling exterior trying to contract upon a heated, expanded interior. The rock not being susceptible of sudden elasticity, the interior refuses to contract in obedience to the demands of the exterior, and when the latter endeavors to contract the passive resistance of the expanded interior causes the surface to crack and break.

Certain rocks, notably granites, exfoliate under extreme temperature changes; that is, the surface portions split off in large sheets, which may be of almost any thickness, and are either flat or, more commonly, are curved. The effect is frequently the disintegration of rocks into minute fragments. This is especially noteworthy in those igneous rocks which are coarsely crystalline.

The force of the wind bearing particles of sand acts like emery and becomes a disintegrating agent of importance. This agency is of small efficiency in regions of ordinary rainfall, because in these the soil is protected and held together by its covering of vegetation, but on sandy coasts the force is intense. In a Cape Cod lighthouse a single heavy gale so ground a plate-glass window as to render it opaque and useless. Glass is far harder than many rocks so that the latter are quite rapidly abraded and cut down by the drifting sand. The softer parts are cut away first, leaving the harder layers, streaks or patches standing in relief. In this way very fantastic forms of rocks are frequently shaped out; pot-holes and caverns are excavated by the eddying drift, and archways cut through projecting masses. Isolated blocks are sometimes so symmetrically cut away on the under side that they come to rest upon a very small area and form rocking stones, which, in spite of their size and weight, may be swung by the hand. Slowly as they work, the wind and temperature changes prevent any complete stagnation in the circulation of material, and thanks to them, the processes of disintegration of rock and transportation of soil are kept up even in the dryest deserts.

"The source of all running water," says Scott, "whether surface or underground, is atmospheric precipitation. The rain-water which falls upon the land is disposed of in three ways: One part is returned to the atmosphere by evaporation, another part flows over the surface to the nearest watercourse, the remainder sinks into the soil to a greater or less depth, and tho some of it is returned to the surface in springs, yet a great part must reach the sea by subterranean channels."

The relative proportions of these three parts of the total precipitation vary much in accordance with the climate and with the topography of the land surface. At a depth below the surface, which varies greatly at different times and places, the soil and rocks are saturated with water, which is called the ground water. Near bodies of surface water it may be very little below the surface of the ground, while in arid regions, with irregular topography, it may sink to great depths. In the eastern United States the ground water is encountered at depths of 1/100 feet, as is shown by the countless wells which are supplied by it. In the plateau of the Colorado River, which is dissected by profoundly deep cañons, the ground water is, in places, nearly 3,500 feet from the surface. The level fluctuates with the rainfall, rising in wet seasons and sinking in dry.

It is usual to regard the ground water as everywhere penetrating to great depths, but as Spurr briefly says: "It is probable that the universal presence of ground water is characteristic of a comparatively shallow surface belt, below which the water which has not been again drawn off at the surface, at a lower level, or has not been used up in hydration processes, is concentrated into the larger fissures."

The factors which determine flow are the inclination of the stratified rocks, the alternation of porous and impervious beds, and the character of the joints and fissures and not surface topography. The water, seeping downward through the joints and bedding planes, exerts its solvent and decomposing action upon the walls of these crevices, in the manner already described in connection with the work of rain. Down to the level of the ground water, or in the shell of weathering, percolating waters are the great agent of decomposition and therefore always contain more or less mineral matter in solution, the nature and quantity of which depend upon the character of the rocks traversed. Below the ground water level in the shell of cementation the effects are more reconstructive than destructive, tho solution and alteration of minerals continue at these lower levels.

In passing through limestone, percolating waters dissolve channels which sometimes enlarge into caverns. The Mammoth Cave, in Kentucky, covers several square miles, and Professor Shaler estimated the length of the passages at 100,000 miles. When underground waters become highly heated through contact with hot volcanic masses their solvent efficiency is greatly increased. Rocks penetrated by such thermal waters are profoundly altered in character and composition.

Except in caverns, underground waters flow too slowly to accomplish direct mechanical erosion, but indirectly they may bring about important mechanical changes. Masses of soil or talus, lying on steep slopes, saturated by long-continued, heavy rains, may have their weight so increased and their friction so reduced as to cause landslides. Rock slides occur in a similar manner. In 1903 at Frank, Alberta, in Canada, the entire face of Turtle Mountain fell and rushed across the valley in a huge avalanche of broken rock, estimated at 40,000,000 cubic yards.

The effect of this seepage appears wonderfully in springs, which are merely the openings of the ground water upon the surface, due to the force of gravity, in that the source of a spring is always higher than its mouth. A spring usually is formed when a relatively impervious bed of rock (usually clay in some form) overlaid by porous rocks crops out on a hillside. The ground water saturates the lower layers of the porous beds until its descent is arrested by the impervious bed, and then the water follows the upper surface of the latter. When, by some irregularity of the ground, the impervious bed comes to the surface, the water will issue as a spring or a line of springs.

Other springs rise through a crack or fissure in the rocks. Inclined porous beds, enclosed between more impervious ones, allow the water to follow them downward. On reaching a fissure opening upward, the water will rise through it and, if it is under sufficient pressure, will reach the surface.

An artesian well is an artificial fissure spring. It is a boring which taps a sheet or stream of the ground water, when the water is under sufficient pressure to rise to the surface or even spout high above it.

The underground streams, of which springs are the outlets, often have effected much in the way of dissolving rock material, and hence spring-water always contains dissolved minerals, principally the carbonates and sulphates of lime and magnesia and the chlorides of magnesium and sodium. In "mineral springs" the quantity of dissolved materials is larger and perceptible to the taste.

The narrow bed of a river has the effect of making its destructiveness more apparent, but as a whole rivers are less potent than the atmospheric agencies. A certain amount of solution and decomposition is performed by rivers upon the rocks of the bed, and in limestones this may be considerable, especially if the water be charged with organic acids from a swamp or peat-bog.

As in the case of the wind, the stream merely supplies the power; the implement with which the cutting is performed is the sand, pebbles and other hard particles which the water sets in motion. These abrade the rocks against which they are cast, just as the wind-driven sand does, but more effectively, because of the ceaseless activity of the stream, and because many rocks are rendered softer and more yielding by being wet. The mechanical work is dependent upon the velocity of the current varying directly as the square of that velocity. Angular blocks are speedily worn into cobblestones and these into pebbles of spheroidal or flat, discoidal form. A process of selection goes on, by which the softer materials are ground into mud, the harder remaining as pebbles and sand.

Sudden fluctuations of volume in a river, so that it is now a rushing torrent and again almost dry, is a much more efficient agent, both of erosion and of transportation, than is one which carries nearly the same quantity of water at all times or which fluctuates only slowly. In eddies and at the foot of cascades the water acquires a rotary motion, which is transmitted to stones lying on the bottom. In a rocky bed these revolving stones excavate cylindrical holes, often of remarkable regularity, called pot-holes, or giant kettles. Unassisted by other agencies, a river cuts a narrow, steep-sided trench or gorge.

As soon as the gorge begins to form, its sides are attacked by the atmospheric destructive forces and a process of widening is begun; but this is very slow and to widen out the gorge or cañon into a broad valley, with gentle slopes, requires a very long period of time, determined by the activity of the climate and the resistant power of the rocks. Rarely is a river valley straight for any considerable distance, but takes a sinuous course, with rocky spurs projecting alternately from opposite sides of the stream. This is true even of swift streams flowing through hard rocks, and the tendency is much exaggerated when the velocity of the current is diminished and the river-bed is in soft materials, as in the lower Mississippi.

Having learned the general character of river erosion, a few concrete examples will be interesting. A particularly valuable case is that of the little river Simeto in Sicily, since the history of its gorge is so well known. In 1603 a great lava flood from Ætna was poured out across the course of the stream, and, when cold, solidified into a barrier of the hardest rock. When Sir Charles Lyell visited the spot in 1828 he found that in a little more than two centuries the stream had cut a gorge through this barrier of 40 to 50 feet deep and varying in width from 50 to several hundred feet. The lava which had thus been trenched is not porous or slaggy, but homogeneous, dense and very hard. In the northern parts of the United States the great ice sheet brought down with it vast quantities of drift that filled up the channels of many streams and quite revolutionized the drainage of certain districts. Since that time the displaced streams have cut out new channels for themselves. Au Sable Chasm, New York, is an example of these geologically modern river gorges, the atmosphere not having had time to widen it.

The Niagara is an exceptional case, the gorge being cut, not only by the direct abrasion of the running water, but also by the action of the spray and frost at the falls. In the ravine the upper rock is a hard, massive limestone, which is underlaid by a soft clay shale. The latter is continually disintegrated by the spray of the cataract and by the severe winter frosts undermining the limestone, which, when no longer able to bear its own weight, breaks off in tabular masses. Thus the falls are steadily receding, leaving behind them a gorge, which is deepened by the river and especially by the plunging masses of water at the foot of the cataract.

One of the most remarkable known examples of river erosion is seen in the cañons of the Colorado. The Grand Cañon is over 200 miles long and from 4,000 to 6,500 feet deep, with precipitous walls. It is extremely probable that the river has been rendered able to cut to such profound depths by the gradual uplifting of the whole region, which is now a lofty plateau, in places more than 8,000 feet above the sea.

The scope of the transporting power of running water is dependent upon the velocity of the current. If the rapidity of a stream can be doubled, it can carry 64 times as much as before, being as the sixth power. The destructiveness of sudden and violent floods is thus explained. In the terrible flood which overwhelmed Johnstown, Pennsylvania, in 1889, great locomotives and massive iron bridges were swept off, it is hardly an exaggeration to say, like straws, and huge boulders carried along like pebbles.

The quantity of material which rivers are continually sweeping into the sea is enormously great. Every year the Mississippi carries into the Gulf of Mexico nearly 7,500,000,000 cubic feet of solid sediment, either in suspension or pushed along the bottom, an amount sufficient to cover one square mile to a depth of 268 feet. In addition to this is the quantity brought down in solution, which is estimated at 2,850,000,000 cubic feet annually. And yet this astounding volume only represents a lowering of the surface of the entire drainage area at the rate of one foot in 4,920 years, for it must be remembered that North America's great river drains 1,325,000 square miles.

In addition to the destructive agencies of the atmosphere and of running water, the sea plays a large part. Upon the coast line, whether it be rock or beach, the waves dash interminably, not only possessing the force which has been imparted to them by the wind but also from the tension of oceanic currents and the tides. According to observations made for the Scotch Lighthouse Board, the average wave pressure on the coast of Scotland is for the five summer months 611 pounds per square foot and for six winter months 2,086 pounds. These are average figures and are greatly exceeded in storms, when the force of the breakers often rises to many tons per square foot.

The gentlest movements have some grinding action among the sands, while the heaviest may dislodge and move along, up the shores, rocks many tons in weight. Niagara wastes its power by falling into an abyss of waters, but in the case of the waves the rocks are bared anew for each successive plunge. The waters are often loaded with gravel and sand when they strike, and thus carry on abrasion. Cliffs are undermined, rocks are worn to pebbles and sand, and, through mutual friction, sand is ground to the finest powder. Rocky headlands on windward coasts are especially exposed to wear, since they are open to the battering force from different directions.

The coast of Yorkshire in England is washed away at an average rate of nearly seven feet per annum. The island of Heligoland, near the German coast, has suffered great loss from the attacks of the sea within historic times; the small eastern island was cut off from the larger island, Heligoland proper, by a great storm in 1720. At Long Branch, New Jersey, the sandy bluffs must be artificially protected against the attacks of the sea; yet in spite of such protection almost every severe gale does considerable damage. Sandy coasts which are low-lying and flat often suffer less from the inroads of the sea than rocky and precipitous ones, but even such coasts may, however, be rapidly cut back. Limestone coasts suffer from solution by sea-water and are characterized by long caverns and tunnels, tho sea caves are worn by the surf in all classes of rocks.

Of far less influence are the lakes, which indeed are to be regarded as merely temporary bodies of water and which either by being filled up or by the gradual wearing away of a barrier which obstructs them will disappear. In the Great Lakes there are small tides and small breakers, which in all details follow the nature of marine destruction, but on a far smaller scale.

It is otherwise, however, with snow and ice; snow in the form of avalanches, which frequently bring down with them masses of earth, and ice in the form of glaciers. "A glacier," says Scott, "is a stream of ice which flows as if it were a very tough and viscous fluid, and does not merely glide down a slope, as snow glides from the roof of a house. Their contribution to the sum total of rock destruction and reconstruction is relatively small, but their former extension has a wide bearing upon some of the most far-reaching of cosmical problems.

"The height, in the Alps, of the snow-line, or that below which the snow annually precipitated melts during the year, is about 8,400 feet on the north side of the Alps and about 8,800 feet on the south side, and the glacier may descend below this line 5,000 feet or more. Tho starting where all is white and barren, it passes by regions of Alpine flowers and often continues down to a country of gardens and human dwellings before its course is ended. Thus the Glacier des Bois, an upper portion of which is called the Mer de Glace, rises in Mont Blanc and other neighboring peaks and terminates like several other glaciers, in the vale of Chamouni. In a similar manner two great glaciers descend from the heights of the Bernese Alps to the Grindelwald valley just south of Interlaken."

Snow is made up of minute, hexagonal crystals of ice, which are intimately mixed with air and thus separated from one another. Ice is composed of the same kind of crystals as is snow, but they are in contact with one another, not separated by air. To convert snow into ice it is only necessary to expel the air and bring the crystals into contact, for which pressure alone is not ordinarily sufficient.

The first step in the transformation is the partial melting of the upper layers of snow. The water thus formed trickles down into the snow beneath, expelling much of the air. This underlying snow has still a temperature much below the freezing point, and the percolating water is soon refrozen into little spherules of ice. This substance, midway between snow and ice, is called névé. The air, which is now in the form of discrete bubbles, is largely expelled by the increasing pressure of the overlying snow masses, which are continually added to by renewed falls, and the névé is thus converted into ice.

A glacier moves in much the same way as a river, but at a very much slower rate. The middle portion moves faster than the sides, because the latter are retarded by the friction of the banks, and, for the same reason, the top moves faster than the bottom. While behaving like a plastic substance under pressure, ice yields readily to tension, and even a slight change in the slope of the bed will cause a great transverse crack, or crevasse, to form. Marginal crevasses are formed along the sides of the glacier and are due to the more swiftly moving middle pulling away from the retarded sides.

The rate of glacier movement depends upon the snow supply, upon the slope of the ground and the temperature of the season. The great stream of ice which enters Glacier Bay in Alaska has a summer velocity of seventy feet per day in the middle.

Newly formed glaciers remove the soil, talus and other loose material from the surface and then the bare rocks are eroded by a double process: The joint-blocks are torn away by the advancing ice, an operation which is much facilitated by the continual liquefaction and relegation of the ice at the bottom of the glacier, owing to changes of pressure, for it must be remembered that the melting point of ice varies with the pressure and this is continually changing, due to the motion of the glacier and inequalities of the bed, and in this manner the joint-blocks of the bed-rock are loosened. The bottom of the glacier is a mass of ice mingled with rocks, pebbles, boulders, sand and débris of all sizes, and by their means the bed-rock is worn down, smoothed, polished and scored with parallel marks in a fashion which forms the unmistakable autograph of the glacier.

"In the lower part of a glacier," says Dana, "the several moraines generally lose their distinctness, through the melting of the ice and also by reason of the fact that the glacier is generally compressed in its lower part to a width very much less than the aggregate width of its tributaries. The surface of the glacier, accordingly, often becomes covered with earth and stones for the greater part of its breadth. The bluff of ice which forms the foot of a glacier is often a dirty mass, scarcely revealing superficially its real nature.

Besides the superficial moraines, a glacier also gathers rock material from the bottom over which it moves. The disintegrated and decomposed rock is mostly scraped from the surface, masses of rock are torn off from jointed ledges, and soft rocks in the path of the glacier are deeply abraded.

The final melting leaves all the earth and stones in unstratified heaps or deposits, which may be further transported, abraded and deposited by the stream that flows from the glacier. The mass of such deposits dropped at the foot of a glacier is called the terminal moraine.

River, lake and coast ice also transport material. When a glacier enters the sea it plows along the bottom until the buoyant power of the water breaks off great fragments of it, which float away as icebergs. These are often of gigantic size, veritable islands of ice, and huge as they appear, only about one-ninth of their bulk is above water. As icebergs are derived from glaciers, they carry away whatever débris the parent glacier had upon or within it, and, wherever they melt, they drop all to the ocean's bottom. The sea about the Newfoundland banks is one of the regions of melting icebergs; and there is no doubt that vast submarine accumulations of such material have been made there by this means.

Organic forces also play a part. Seeds germinating in the crevices of rocks, or the roots of trees which invade such crevices from above, wedge the rocks apart with the same irresistible power as is displayed by frost, and often large areas of rock are thus most effectively broken up. Many marine animals bore into rocks, even the hardest, and cause them to crumble, and on the land great numbers of animals continually bore and tunnel through the soil, allowing a freer access of air and water. In the tropics the soil is fairly alive with the multitude of burrowers.

Earthworms are among the most important agents in work of this kind. The worms swallow quantities of earth for the sake of the organic matter which it contains and grind it exceedingly fine in their muscular gizzards. This ground-up soil is always deposited on the surface, in the form of the coiled "worm-castings" so abundant in grassy places. In England the material thus yearly brought to the surface varies from seven to eighteen tons per acre, which means an average annual addition of one-tenth to one-sixth of an inch. In the tropics ants and termites (so-called white ants) are even more active than worms in tunnelling the soil, and in many semi-arid plains burrowing mammals in incredible multitudes are continually working over the soil to great depths, as in the prairie-dog villages of our Western plains. The occasional heavy rains thus penetrate to depths which could not otherwise be reached.

The immense influence exerted by man upon the changing condition of Physical Geography has been summarized by Geikie. The great geologist regards him as a factor antagonistic to the methods and designs of Nature. "Not content with gathering the fruits and capturing the animals she has offered for his subsistence," he says, "Man has, with advancing civilization, engaged in a contest to subdue the earth and possess it. His warfare, indeed, has often been a blind one, successful for the moment, but leading to sure and sad disaster. He has, for instance, stripped off the woodland from many a region of hill and mountain, gaining his immediate object in the possession of their stores of timber, but thereby laying bare the slopes to parching droughts or fierce rains. Countries once rich in beauty and plenteous in all that was needful for his support are now burnt and barren or washed bare of their soil. It is only in comparatively recent years that he has learned the truth of the aphorism, 'Homo Naturæ minister et interpres.'

"Human interference affects meteorological conditions by removing forests and laying bare to the sun and winds areas which were previously kept cool and damp under trees, or which, lying on the lee side, were protected from tempests; by drainage, the effect of this operation being to remove rapidly the discharged rainfall, to raise the temperature of the soil, to lessen the evaporation, and thereby to diminish the rainfall and somewhat increase the general temperature of a country; by the other processes of agriculture, such as the transformation of moor and bog into cultivated land and the clothing of bare hillsides with green crops or plantations of coniferous and hardwood trees.

"By increasing or diminishing the rainfall, man directly affects the circulation of water over the land; by the drainage operations, which cause the rain to run off more rapidly than before, he increases floods in rivers; by wells, bores, mines or other subterranean works, he interferes with underground waters and consequently with the discharge of springs; by embanking rivers, he confines them to narrow channels, enabling them to carry their sediment farther seaward, and in a thousand other ways his influence is felt."

CHAPTER X

RECONSTRUCTIVE PROCESSES

It has been pointed out, in the work of "destruction," that in the true sense of the word it is not destruction at all, but rather a preparation for building anew. It is at the same time the closing of one period of existence for a certain group of particles of matter and the beginning of another. But while the active agencies that lead to the breaking down of former masses are numerous, in the strict sense of the word the reconstruction agency is only one—that of sedimentation. The new rock is built out of the old, tho under differing conditions and with different results.

At the present time it is estimated about one-half of the waste of the land is carried directly into the sea, while the remainder is arrested in its journey and deposited upon the land. The accessible rocks of the earth's crust are more largely composed of marine deposits than those laid down in other ways, yet the non-marine sedimentary rocks are also extensively represented. A natural division of the sedimentary accumulations is into the marine and the continental, including in the latter the deposits which are made upon the land, or in such bodies of water as are not parts of the sea.

"It is an almost universal characteristic of sedimentary accumulations," says Scott, "whether modern deposits or ancient rocks, that they are stratified; that is, divided into more or less parallel layers or beds. Stratification is due to the sorting power of water, or of the wind, by which, so long as conditions remain the same, particles or fragments of similar size and weight are thrown down at the same spot. Layers clearly demarcated from one another may be produced in either one of two ways: (1) By such a change of conditions that the material deposited changes abruptly, tho perhaps only as a mere film of a different substance; or (2) by a pause, however brief, in the process of deposition. The planes of contact between the successive layers, which may be indistinct or very sharply defined, are called the bedding or stratification planes." Each bed is made up of some predominant substance in a state of greater or less purity, such as gravel, sand or clay, due to the sorting powers of the water, and thus heterogeneous material is separated into its constituent parts, tho the separation is rarely quite complete, and sometimes there is hardly any separation at all. In the sea, or a large lake, the material on the bottom grows finer outward from the shore, while a river, whose velocity diminishes from headwaters to mouth, lays down material of decreasing coarseness, from the boulders and cobbles of the headwaters to the fine silt of the lower course.

Wherever a sandy soil occurs, unprotected by vegetation, as in deserts or along the seacoast, the wind drifts the sand and piles it up into hills or sand dunes. When the sands are mixed with pieces of shells and other calcareous material, percolating waters, by dissolving and redepositing the carbonate of lime, may cement the sands into firm rock. This is the more conspicuous when the whole material is calcareous, as in the shell sands of Bermuda.

Springs also form siliceous deposits, but they are rare, and the carbonate of iron is deposited as chalybeate. Phosphate deposits are also made in rainless regions, where guano, the accumulated excrement of birds, piles up to great thicknesses without the loss of its soluble matter. Cave deposits are usually chemically formed, and are due to the solution and redeposition of carbonate of lime. At first, the deposit is white, opaque, and very friable, crumbling at a touch, but repeated depositions fill up the interstices of the porous mass and convert it into a hard, translucent stone, which assumes a crystalline structure through the development of calcite or aragonite crystals.

The masses thus formed that depend from the roof of the cavern are called stalactites. After hanging for a time from the roof the drop of water falls to the floor of the cave, and there, in similar fashion, deposits a little layer of carbonate of lime, which gradually grows into a cone. This is a stalagmite, and differs from the stalactite only in the fact that it grows upward from the floor instead of downward from the roof. The stalagmite is, of course, exactly beneath the stalactite, and as long as the water continues to follow the same path the two cones are steadily, tho very slowly, increased both in height and thickness, until they meet, unite, and form a pillar extending from floor to roof of the cavern. These deposits form the curious and beautiful features of limestone caverns.

The vegetable accumulations are the most important of the swamp and bog deposits, for the preservation of which a certain amount of water is necessary. The vast quantities of coal which occur in so many parts of the world testify to the significance of the part which bog and swamp accumulations of vegetable matter have played in the earth's history. The nearest approach to coal in process of formation at the present day is in the peat bogs, which are especially abundant and extensive in cool, damp climates, as in Ireland, Scandinavia, and the northern parts of South America.

The Great Dismal Swamp of Virginia and North Carolina probably more nearly reproduces than do most existing peat bogs the conditions of the ancient coal swamps. The swamp, which measures thirty miles by ten, is a dense growth of vegetation upon a water-covered soil of pure peat about fifteen feet deep, and with no admixture of sediment. The swamp cypress grows abundantly in the bog, and prevents, by its dense shade, the evaporation which would take place in summer could the sun's rays penetrate to the wet soil. The shallow layer of water which covers the ground receives the fallen leaves, twigs and branches, and sometimes even the trunks of fallen trees, preventing their complete decomposition, while the dense covering of mosses, reeds and ferns which carpet the ground add their quota to the mass of decaying vegetable matter.

The accumulations at the mouths of rivers, generally known as deltas, have, from ancient times, been the means of showing Man in what manner the configuration of the surface of the earth was changing. The delta at the mouth of the Nile is a typical case in many ways, and its working was observed by the older nations that bordered the Mediterranean. This is more especially noticeable in the Nile, for there was added to the problem the question of why the delta did not advance further into the sea (due to a swift current along the sea front), and this led to an investigation of the Mediterranean currents.

But the delta of the Mississippi, on the other hand, is advancing rapidly, about 110 yards a year, or 27 feet a month, a speed which, if it be extended to long geological ages, is amazing. Extraordinary tho it may seem, a week's stay at the mouth of the Mississippi is enough to see perceptibly the surface of the Earth changing shape. Débris brought down by the Indus, a swifter stream, instead of forming a delta with a sluggish current, has been carried to the ocean, where it has made a shoal covering an area of 700,000 square miles, a little larger in size than all the States north of Mason and Dixon's line and west of the Mississippi, or five times as large as the British Isles. In the course of time this shoal will rise to the surface, and a new country will have been formed.

The delta formation is seen in small streams entering lakes, and accumulations in the same manner as are made in the ocean beds are to be found in the lake basins. In small lakes the coalescence of deltas, or the advance of a single one, will eventually fill up the basin, forming first swamps and then smooth, grassy meadows, through which flow the streams, keeping their own channels clear. Such filled-up lakes are common in many mountain valleys.

Lake deposits betray the form of the basin in which they are laid down. Around the old shore line are masses of coarse materials, with deltas interspersed, to mark the mouths of streams, while toward the middle of the basin quantities of fine mud and clay have accumulated. An excellent example of such a deserted lake basin is that known as Lake Bonneville, in Utah, of which Salt Lake is the shrunken remnant. The drying up of this lake, which was once fresh, and had an outlet northward to the Snake River, is an event geologically so recent that its form and size, its shores and islands, its high and low stages—in short, its history—can be made out with great clearness, as has been admirably done by Mr. Gilbert of the United States Geological Survey. At its time of greatest extension Lake Bonneville had an area of 19,750 square miles and a maximum depth of 1,050 feet, while Salt Lake (which is variable) had in 1869 an area of 2,170 miles and an extreme depth of 46 feet. Around the ancient shores are preserved the terraces, embankments and deltas of the various stages of water, with the gravels and sands appropriate to the shallow water.

"The sea is the great theater of sedimentary accumulation," says W. B. Scott in his "Introduction to Geology," "and rocks of marine origin form the larger part of the present land surfaces. Important as other classes of deposits may be, they are less so than those laid down in the ocean and the waters immediately connected with it. Marine deposits may be classified primarily in accordance with the depth of water in which they were laid down, one of the most valuable guides to the history of ancient rocks, and secondarily in accordance with the nature of the material of which they are composed and the processes by which they were accumulated.

Ripple marks are formed by the wind or by the rippling movement of water, and may be seen on any sandy beach. They occur especially in sands, in shoal-water deposits, as well as in those made on flood plains and in lakes and on sand dunes. They are found in rocks of all geological periods, and tho most frequent in sandstones, occur in other kinds of rocks. Wave marks and rill marks, sun cracks, rain prints, and the tracks of land animals, are preserved in a similar way. It might seem incredible that such slight marks could be preserved for ages in the solid rocks, were it not for the fact that their occurrence is so common.

Where for long distances no large rivers enter the sea, and the material is all derived from the wear of the coast, the arrangement of coarse and fine deposits is quite regular, and gravel beds may extend as far as ten miles from land. Waves and current sweep sediment not only toward the shore, but parallel with it, and tend to simplify the coast line by building barriers and spits across the mouths of bays, which the waves may pile up above high tide, as is seen all along the eastern coast of the United States. Behind these barriers streams bring in sediments, filling up the bays and converting them into salt marshes, and eventually into land.

Very near shore currents produce irregularities of stratification, especially the structure known as cross bedding. Nor are the deposits of lime which go to make limestones deposited at the bottom of the sea by organic forms with calcareous exteriors, such as shellfish, starfish, and the coral polyps, to be forgotten. For example, the chalk "white cliffs of Dover," which are so characteristic a feature of the coast of the South of England, are composed mainly of tiny shells, many of them so unbroken that they can be picked out by hand, while the whole structure, under a microscope, is seen to be of this order. The creation of huge groups of islands and the extension of the mainland in tropical and sub-tropical waters by the coral polyp is constant.

The fine material derived from the land is generally termed "mud." The color of the mud is different on different parts of the ocean floor. It is blue, red, and green, according to the prevailing coloring matter.

The Abysmal deposits are those the materials of which are not directly derived from the land, but consist of matters carried to the sea in solution and extracted from the sea-water by the agency of organisms, together with volcanic substances in a more or less advanced stage of decomposition. They are generally termed oozes, the most important of which is Foraminiferal Ooze. The Foraminifera are minute animals, each one a tiny speck of jelly, most of which, in spite of their extreme simplicity of structure, have the power of secreting very beautiful and complex shells of carbonate of lime. As the animals die the shells settle to the bottom in myriads.

Silica is also dissolved in sea-water, and various organisms construct their tests of that substance. The Radiolaria are, like the Foraminifera, a group of microscopic, unicellular animals, which secrete siliceous tests of the most exquisite delicacy and beauty; they live both at the surface and at the bottom of the sea. Radiolarian tests may be detected in all sorts of marine deposits of both deep and shallow water, but it is only in very profound depths that they occur in quantity sufficient to give character to the deposit. In the Antarctic Ocean there is an extensive belt of Diatom ooze, resembling the fresh-water deposit, but may be distinguished by the presence of foraminiferal and radiolarian shells and tests.

The profoundest abysses of the ocean, far from any land, are covered with a deposit of red clay, which, tho varying much in composition and color, is yet of a quite uniform character. The clay is derived from the disintegration and decay of volcanic substances, especially pumice, which floats upon water, often for months, and drifts long distances in the ocean currents. Of all the oceanic deposits the red clay is the most widely extended, covering 51,500,000 square miles of the bottom. The excessive slowness with which this abysmal deposit is formed is shown by the occurrence in recognizable quantities of meteoric iron.

"Comparing the marine deposits now accumulating in the sea with the rocks of evidently marine origin which form most of the land," concludes Scott, "we find that the great bulk of these rocks, the sandstones, slates, and limestones, are such as are formed in water of shallow and moderate depths, while only rarely do we discover a rock that implies really deep water."

CHAPTER XI

THE INTERIOR OF THE GLOBE

STRUCTURAL GEOLOGY in many ways is the most intricate of all the divisions of the science, for the reason that all the various factors come into play. Thus while it deals with the substances of which the earth's crust is composed—it is far from being merely descriptive—it must at the same time present, as far as possible, the causes of their placement and the forces which have gone to make up their structure.

The object of Structural Geology is to learn not only the agencies which have produced the structures and the way in which they operated, but also the successive steps by which the rocks originated, the order in which they occurred, and their geological date. The distinction between a rock and a mineral is not always an easy one to grasp, yet it is essential that it should be so. A rock is any extensive constituent of the earth's crust, which may consist, tho rarely, of a single mineral, but in the great majority of cases is a mechanical mixture of two or more minerals. A rock thus has seldom a definite chemical composition or homogeneous internal structure. An examination with the microscope almost always shows that a rock is an aggregate of distinct mineral particles, which may be all of one kind or of many different kinds, in varying proportions. Geologically, incoherent masses of sand and clay are regarded as being rocks quite as much as the hardest granites.

The Igneous Rocks, wherein heat is the chief factor in their making, as the name shows, are truly primary rocks, in the sense that it seems that all others have been made from them. The particles of matter now composing sedimentary and metamorphic rocks have been changed so often that in many cases the relationship to the igneous rock is not easy to trace, but it is there.

As geology is primarily a historical study, the most logical scheme of classification is obviously one that, so far as possible, is genetic; that is to say, one which expresses in brief the history and mode of formation of the rocks. This genetic principle would suggest the division of all rocks into three primary classes or groups: (a) Igneous Rocks, those which were melted and have solidified by cooling; (b) Sedimentary Rocks, laid down under water by mechanical, chemical and organic processes; and (c) Metamorphic Rocks, which have been profoundly changed from their original sedimentary or igneous character, often with the formation of new mineral compounds in them.

The rocks of earliest times, called igneous, have a deep-seated origin and have either forced their way to the surface or have cooled and solidified at varying depths beneath it. They were the first to be formed, and all the others have been derived, either directly or indirctly, from them. The products of the chemical decomposition or mechanical abrasion of the rocks have furnished the materials out of which the sedimentary rocks were formed, at least in the first instance.

The igneous rocks are massive, as distinguished from stratified, and tho sometimes presenting a deceptive appearance of stratification, may always be distinguished from the truly stratified rocks. Characteristic differences appear between those igneous masses which have solidified deep within the earth, called "plutonic," and have been brought to light only by the denudation and removal of the overlying rock masses, and those which have cooled at or near the surface of the ground, known as volcanic.

In order to determine the circumstances under which the rock was formed, the texture of a rock must be observed, and hence great attention is paid to it; and in the igneous group five principal types of texture will be found: 1. Glassy.—A glass or slag without distinct minerals in it, tho the incipient stages of crystallization, in the form of globules and hairlike rods, are often observable with the microscope. When the glass or slag is made frothy by the bubbles of escaping steam and gas the texture is said to be vesicular, scoriaceous or pumiceous, according to the abundance of the bubbles. 2. Compact (or Felsitic).—Characterized by the formation of exceedingly minute crystals, too small to be seen by the unassisted eye, giving the rock a homogeneous but stony and not glassy appearance. 3. Porphyritic.—In rocks of this texture are large, isolated crystals, called phenocrysts, embedded in a ground mass, which may be glassy or made up of small crystals. They have usually solidified near the surface of the ground. 4. Granitoid.—In this texture the rock is wholly crystalline, without ground mass or interstitial paste. The component grains, which may be fine or very coarse, are of quite uniform size, and as the crystals have interfered with one another in the process of formation they have rarely acquired their proper crystalline shape. They have solidified slowly and at great depths. 5. Fragmental.—This is represented by the accumulations of the fragmental products ejected by volcanoes, agglomerates, bombs, lapilli, ashes, etc.

The texture of an igneous rock is determined by the several factors which affect the molten mass during consolidation. Of such factors may be mentioned the chemical composition, temperature, rate of cooling, degree of pressure, and the quantity present of dissolved vapors and gases, which are called mineralizers. Chemical composition determines the fusibility of a rock at a given temperature. The effect of chemical composition upon texture is seen in the rapidity with which the less fusible rocks chill and stiffen, and therefore the greater frequency with which they form glasses. Hence very rapid cooling results in a glass, but the microscope reveals the incipient stages of crystallization in many of even the glassy rocks. A somewhat slower rate of solidification produces a cryptocrystalline rock, and successively slower rates bring about the porphyritic, microcrystalline and granitoid textures.

Pressure is of importance in preventing the rapid escape of the vapors and gases contained in the molten mass, and hence frothy, scoriaceous and vesicular textures cannot be produced under high pressures. The mineralizers, such as steam, hydrochloric acid, and other vapors, determine the crystallization of many minerals which refuse to crystallize in the absence of such vapors. It must not be supposed that a molten magma consists merely of a number of fused minerals mechanically mixed together and having no effect upon one another. Petrographers believe that a molten magma is a solution of certain compounds in others, and that crystallization occurs in the order of solubility, as the point of saturation for particular compounds is successively reached by the cooling mass.

Prof. Kemp has determined the order of formation of minerals in a solidifying magma. First to form are apatite, the metallic oxides (magnetite, ilmenite), and sulphides (pyrite), zircon and titanite. "Next," he says, "come the ferro-magnesian silicates, olivine, biotite, the pyroxenes and hornblende. Next follow the felspars and felspathoids, nepheline and leucite, but their period often laps well back into that of the ferro-magnesian group. Last of all, if excess of silica remains, it yields quartz. It results from what has been said that the residual magma is increasingly siliceous up to the final consolidation, for the earliest crystallizations are largely pure oxides. It is also a striking fact that the least fusible minerals, the felspars and quartz, are the last to crystallize."

The classification of the igneous rocks now most generally adopted is made upon a threefold method, according to texture and chemical and mineralogical composition. In the following table (modified from Kemp's) the textures are given in vertical order, while transversely the arrangement is mineralogical, chiefly in accordance with the principal felspar.

The division of the igneous rocks into families is made primarily in accordance with the mineralogical composition, with subdivisions according to texture. This method gives us five principal groups: (1) The Granite Family. This family includes the dark volcanic glass, Acidic —> CLASSIFICATION —> Basic

Surface Flows	Glassy	Acid Glasses Obsidian, Perlite, Pumice, Pitchstone			Andesite Obsidian					Basic Glasses, Scoriæ, Tachylite, Basalt Obsidian	
		Chief Felspar Orthoclase			Chief Felspar Plagioclase				Nepheline Leucite	No Felspar	
		Biotite and or Hornblende and or Augite			Biotite and or Hornblende		Pyroxenes			Augite and or Hornblende and or Biotite	
		+ Quartz	—Quartz	Leucite Nepheline	+ Quartz	—Quartz	—Olivine	+ Olivine	—Olivine + Olivine	—Olivine	+ Olivine
Surface Flows, Thin Sills, Dykes, Laccoliths	Glassy, Compact, or Porphyritic with few Phenocrysts	Rhyolite (Felsite, Quartz-Porphyry) Rhyolite-Porphyry	Trachyte (Felsite) Trachyte Porphyry	Phonolite (rare) Leucite Rocks (Very rare) Phonolite-Porphyry	Dacite (Felsite) Dacite-Porphyry	Andesite (Felsite) Andesite-Porphyry	Augite-Andesite, Basalt (Diabase) Augite-Andesite-Porphyry	Olivine-Basalt, Olivine-(Diabase) Basalt-Porphyry	A series of Nepheline and Leucite Basaltic Rocks, very rare in America	Augitite Augitite-Porphyry	Limburgite Limburgite-Porphyry
Dykes, Sills, Laccoliths	Porphyritic with abundant Phenocrysts	Granite-Porphyry	Syenite Porphyry	Nepheline-Syenite-Porphyry	Quartz-Diorite-Porphyry	Diorite-Porphyry	Gabbro-Porphyry	Olivine-Gabbro-Porphyry		Pyroxenite-Porphyry	Peridotite-Porphyry
Batholiths, Laccoliths	Granitoid	Granite	Syenite	Nepheline-Syenite, Leucite-Syenite (Very rare)	Quartz-Diorite	Diorite	(Diabase) Gabbro	(Olivine-Diabase) Olivine-Gabbro	Theralite (exceedingly rare)	Pyroxenite	Peridotite
	SiO_2	80—65%	65—55%	60—50%	70—60%	65—50%	50—45%		50—40%	55—30%	
		Granite fam.	Syenite family		Diorite family		Gabbro family			Peridotite family	

obsidian; pumice, which is generally known; rhyolite, quartz porphyry and granite. (2) The Syenite Family. The chief rocks included are syenite obsidian, trachyte, phonolite, syenite and nepheline syenite. (3) The Diorite Family. There are but three important rocks in this class, andesites, dacites, and the diorites. (4) The Gabbro Family. This includes basalt, which is a name covering many varieties. They are common volcanic rocks and are thrown out now by the most active volcanoes. (5) The Peridotite Family, embracing pyroxenite, hornblendite, and, after alteration, the Serpentites.

The Sedimentary rocks are secondary formations. They are formed of the débris of the Igneous rocks as the latter have been worn away by the destructive agencies of the atmosphere and water, so that, having been laid down usually under water, they are almost always stratified, and are formed with rounded fragments rarely crystalline. The great bulk of the sedimentary materials consists of simpler and more stable compounds than the igneous minerals from the decomposition of which they have been derived.

The most useful classification of the sedimentary rocks is, primarily, according to the mode of their formation. This gives two principal divisions: I, the Aqueous Rocks, or those laid down under water; II, the Æolian Rocks, those which are accumulated on land, which are of more limited extent and importance. The rocks laid down under water form the larger and more important part of the sedimentary series.

From the accumulation of débris derived from the destruction of preëxisting rocks, carried in mechanical suspension by moving water, whether waves, currents or streams, and dropped when the velocity of the moving water was no longer sufficient to carry them, a certain group of the Aqueous Rocks has been formed. Such accumulations are forming to-day in all kinds of bodies of water, and an examination of the rocks will show that similar accumulations have been made since the beginning of recorded geological time. Mineralogically, the mechanical deposits are of two principal kinds, the siliceous and the argillaceous. The sorting power of water has been sufficient to separate them more or less completely. Sand, sandstone, gravel and conglomerate are in the siliceous group, and clay, mud, mudstone and shale are the Argillaceous Rocks.

. The chemical precipitates are locally restricted, and not at all comparable to the great masses of mechanical and organic sediments. This arises from the fact that the chemical processes occur in a conspicuous way only around the mouths of certain classes of springs and in closed bodies of water without outlet and subject to evaporation. Thus calcareous tufa, oölite, gypsum and rock salt are alkaline, Geyserite and chert (flint) are siliceous, while bog and lake iron ore are ferruginous precipitates.

Limestone, shell marl, chalk, dolomite and green sand are calcareous accumulations, formed almost entirely by the accumulation of vegetable matter and its progressive tho incomplete decay under water. This decay is of such a nature that the gaseous constituents diminish while the carbon is removed much less rapidly; consequently the proportion of the latter substance steadily rises. All the varieties of carbonaceous rocks pass into one another so gradually that the distinction between them seems somewhat arbitrary. From fresh and unchanged vegetable matter to the hardest anthracite there is an unbroken series of transitions. The three main divisions are peat, lignite or brown coal, and black coal.

Æolian Rocks form less of the earth's crust than do the aqueous rocks, but they have a special importance because of the hints which they often give as to the physical geography of the place and time of their formation. Blown sand, forming dunes, drift-sand rock, talus, soil and loess are all of Æolian origin.

Examined with reference to the simplest and broadest facts of structure, it will be noted that rock masses fall into two categories: (1) Stratified Rocks, and (2) Unstratified or Massive Rocks. The stratified rocks form more than nine-tenths of the earth's surface, and if the entire series of them were present at any one place they would have a maximum thickness of about thirty miles; but no such place is known.

As sedimentary strata were laid down upon one another in a more or less nearly horizontal position, the underlying beds must be older than those which cover them. This simple and obvious truth is termed the Law of Superposition. It furnishes the means of determining the chronology of rocks, and tho other methods of ascertaining this point are employed, they must all be based originally upon the observed order of superposition. "The only case," says Geikie, "in which the apparent superposition may be deceptive is when the strata have been inverted, as in the Alps, where the rocks composing huge mountain masses have been so completely overturned that the highest beds appear as if regularly covered by others which ought properly to underlie them. But these are exceptional occurrences, wherein the true order can usually be made out from other sources of evidence."

The stratified rocks which form the land have been changed, at least relatively, from the position which they originally occupied, since the great bulk of them were laid down under the sea. Originally they must have been nearly horizontal, for this is a necessary result of the operation of gravity. Just as a deep fall of snow, when not drifted by the wind, gradually covers up the minor inequalities of the ground and leaves a level surface, so on the sea-bottom the sediments are spread out in nearly level layers, disregarding ordinary inequalities.

The displacements to which strata have been subjected after their formation are of two principal kinds: (1) In the first kind the strata have been lifted vertically upward, often to great heights, without losing their horizontality. In some of the lofty plateaus through which the Grand Cañon of the Colorado has been cut almost horizontal strata are found 10,000 feet above the sea-level. (2) More frequent and typical are the displacements of the second class, by which the beds are tilted and inclined at various angles.

The double condition of a semi-rigid crust with a fluid strata below, coupled with the phenomenon of cooling and contracting, renders the rocks of the earth susceptible to intensely heavy stresses, and breakage is inevitable, dislocation often occurring. But in all parts of the earth's surface the rocks are to be found in strata, so that when such a break occurs it interferes with the continuity of the strata. Where such is not the case, but the rock merely cracks open without any alteration of the levels of the various strata, it is called a "fissure"; but when the strain has been vertical as well as horizontal (it is usually so), the result is to change the consecution of the strata. This is called a "fault."

"Whenever the rocks of the earth's crust are subjected to strain," says J. E. Spurr, "fractures take place in them as in any other body under similar conditions, and the different parts of the rock tend to move past one another along the fracture-planes, seeking to obtain relief from the strain and to accommodate themselves to new conditions. In this movement one part of the fractured rock-mass may move upon the other in any direction—up, down, sidewise or obliquely—according to the conditions, which are different in each instance."

The throw of faults varies greatly in different cases, from a fraction of an inch up to thousands of feet. In those of small throw the plane of fracture is frequently a clean, sharp break; but in the greater faults the rocks in the neighborhood of the fault are often bent, crushed and broken, forming a confused mass of fragments. In the present state of knowledge, however, any scheme of classification has an undue appearance of exactness.

Radial Faults are those in which the principal component of the movement has been upward, downward, or both, tho subordinate movements of tilting and rotation frequently occur. Normal Faults (also called gravity faults) are those in which the fault-plane inclined toward the downthrow side, which forms the hanging wall. "It seems best to use the term normal," says J. A. Reid, "to cover those faults in which, using the horizontal plane as datum, the hanging wall has dropped relative to the foot." Strike-faults are those which run parallel or nearly so to the strike of the beds. Dip-faults are, in general, parallel to the dip of the beds, and therefore cross or branch out from the strike-faults of the same region, more or less at right angles; they are less important than strike-faults, having generally a smaller throw and less length. Dip-faults do not always follow the dip, and strike-faults often deviate considerably from the strike of the beds; and sometimes the fault is neither one nor the other, but midway between the two, and then is called an oblique fault. A reversed fault, which almost always coincides with the strike of the beds, implies a local compression, for the beds occupy less space than before dislocation.

In Horizontal Faults the principal direction of movement is horizontal, and in horizontal strata may readily escape detection. In faults of the preceding groups there is apt to be more or less rotation because of unequal friction and resistance of the walls, but in certain cases this movement of rotation is the principal one, exceeding any movement of translation; and these are the pivotal faults.

A thrust is like a reversed fault, in that it is the result of compression and that the inclination or hade of the fault is toward the upthrow side, which is the hanging wall, but differs in the tendency to a horizontal position of the plane of fracture and in the association with violent folding and plications. In his latest work on the subject B. Willis divides thrusts into the following three groups:

"Scission-thrusts are those in which the fault-plane is independent of any older structures, and occur chiefly in the crystalline schists (metamorphic rocks) and granite, and, as a rule, depart but little from horizontality. Thrusts of this kind are developed on a great scale in the southern Appalachians, especially in eastern Tennessee, where thrusts of 20 miles or more have been observed. On an even more gigantic scale they occur in the Highlands of Scotland and Norway, where the movement of translation amounts to 75 miles.

"Fold-thrusts are intimately connected with folds, and occur only among folded sedimentary rocks; they may arise by plication and inversion, usually between an overturned anticline and the adjoining synclines.

"Surface-thrusts, as their name implies, are formed at the earth's surface, where a rigid, gently inclined stratum that crops out of the ground is subjected to lateral compression and thrust forward over the underlying beds."

The causes of crystal deformations are very obscure, and there is much difference of opinion concerning them. When strata are buried under a sufficient depth of overlying rock to crush them they become virtually plastic, and yield to the compressive force by bending. The movement would seem not to be a true molecular flow, but rather a gliding of the mineral particles one upon another. Geologists accordingly distinguish a shell of flowage, in which the rocks all yield plastically a more superficial shell of fracture, in which all but the softest rocks break on compression, and between the two a shell of fracture and flowage in which some rocks break and others bend, according to their rigidity. The depth of the zone of flowage is estimated at 20,000 to 30,000 feet below the surface.

One explanation made by Willis is that such phenomena are developed in regions that have been raised by upwarping above a position of adequate support, whence results a system of fractures and the settling and readjusting of the fault-blocks.

Quite a different type of explanation seeks to account for the phenomena of faulting by the transfers of molten magmas deep within the earth. "Not only are the violent migrations of igneous material the cause of complex faulting," says J. A. Reid, "but also it is most reasonable to conceive that the deeper and more gradual movements of the subcrust are the cause of the larger fault systems. Given this cause of faulting, the heretofore puzzling facts are satisfactorily and easily explained. Compression and tension still remain true causes of faulting, but mainly as local and proximate ones. The common expression, tilting of fault-blocks, attains a deeper significance, for this tilting may be more largely the result of subcrust migrations than of mere force of gravity. Cases of horizontal motion and pivotal motion become simple, for there is no necessary unchangeable relation between the direction of the force and the position of the fracture-plane."

A modification of this hypothesis has been proposed by Professor Chamberlin, who regards the downward movements of segments of the earth's crust as primary and the horizontal movements as incidental to the former.

Rocks are not to be considered as unbroken solids, even the hardest and most compressed of them, for the reason that they are all interspersed with tiny crevices and sometimes larger cracks, which, as they bear a definite relation to the structure of the whole strata, are known as joints. Some of these, known as "master joints," extend immense distances below ground and form a natural beginning for quarrying stone, but there are usually also "minor joints" as well. In igneous rocks this is obviously due to the contraction on cooling.

But there is a great deal of irregularity or "unconformity," as it is usually called, in the rocks themselves. Strata which have been laid down with but little interruption, which are parallel to the bedding places, and on which the movements of the earth's crust have operated in a uniform manner, show by their structure the comparative peace in which they have lain, and are said to be "conformable"; but where two groups are found which have been differently acted upon by reason of having been laid down in different periods, then these two groups are not conformable with each other, and their relation is known as "unconformity."

Volcanoes, like all other mountains, are subject to the destructive effects of the atmosphere, rivers, and the sea. In the Pacific States may be found admirable examples of volcanic cones in various stages of erosion, notably Mt. Shasta and Mt. Rainier. These mountains, however, merely exemplify the earliest stages of degradation; as time goes on, the loftiest cones will be worn away, and at last only the worn-down and hardly recognizable stump of the volcano remains, which is known as a volcanic neck. The neck consists of the funnel or vent filled up with the hardened lava of the last eruption. The diamond mines of South Africa are in almost cylindrical pipes, which are cut through stratified rocks and are filled with an irregular agglomerate. On the surface the pipes show no topographical indication of their presence, but are quite level with the ground. Lava Flows and Sheets which were poured out on the surface of the ground may be recognized at a glance and traced to the vent whence they issued. Fragmental products are positive proof of volcanic action, for they cannot be formed underground.

The Plutonic Rocks form a series which no one has ever observed in the course of formation, because they were solidified at greater or less depths underground. Tho these unstratified masses cannot be observed in the process of formation, as may the lavas and pyroclastic rocks, yet the nature of the rocks themselves, and their relations to the volcanic and stratified rocks, afford a satisfactory explanation of themselves.

A primary division of the plutonic masses is into (1) injected and (2) subjacent bodies. "An injected body," says R. Daly, "is one which is entirely enclosed within the invaded formations, except along the relatively narrow openings to the chamber where the latter has been in communication with the feeding reservoir." Subjacent bodies, on the other hand, have no floor upon which the intrusive mass rests, the communication with the earth's interior being by great openings which enlarge downward indefinitely within the limits of observation.

Injected Bodies are of manifold variety of shapes and sizes, and differ in their relations to the enclosing or country rock, and different terms are accordingly used to describe them. A dike is a vertical or steeply inclined wall of igneous rock which was forced up into a fissure when molten and there consolidated. Dikes of a certain kind may actually be seen in the making, as when the lava column of a volcano bursts in its way through fissures in the cone.

Intrusive Veins are smaller and more irregular, frequently branching fissures which have been filled with an igneous magma; they may be only a few inches in thickness, and may often be traced to the mass which gave them off. Sills or Intrusive Sheets are horizontal or moderately inclined masses of igneous rock, which have small thickness as compared with their lateral extent. Sheets conform to the bedding-planes of the strata, often running long distances between the same two beds; but if they can be traced far enough they may generally be found cutting across the strata at one point or another. In thickness they vary from a few feet to several hundreds of feet. The Palisades of the Hudson are formed by a sheet of unusual thickness; its outcrop is 70 miles long from north to south, and its thickness varies from 300 to 850 feet.

A laccolith is a large, lenticular mass of igneous rock, filling a chamber which it has made for itself by lifting the overlying strata into a domelike shape; the magma was supplied from below through a relatively small pipe or fissure. The rock of which laccoliths are made is nearly always of the highly siliceous and less fusible kinds, so that it can more easily lift the strata than force its way between them.

Batholiths are great masses of plutonic rock hundreds or even thousands of miles in extent; in general characteristics they agree with stocks, except for their very much greater size. Granite is the commonest batholitic rock, and in such masses forms the core of many great mountain ranges like the Sierra Nevada and the Rocky Mountains.

Much has been said of the manner in which rocks are cut down and built up again by the destructive agent of atmosphere and water, but there is another force which has led to the transformation of a rock from its original form, and this is known as Metamorphism. The term is somewhat vague, for so many factors enter into the making of metamorphic rocks, and the process took place so many aeons ago, that it is all but impossible to gain a clear conception of the manner in which they have come into being. An increase in hardness and in the degree of crystallization occurs, and not infrequently includes the generation of an entirely new set of minerals, characteristically arranged. Whether the original of the rock so metamorphosed was igneous or sedimentary cannot always be determined.

Metamorphism, as classified by Scott, is of two quite distinct kinds: (1) Contact or local, and (2) regional metamorphism. "Contact metamorphism," he says, "is the change effected in surrounding rocks by igneous magmas. There is a difference between the effects produced by a surface lava flow and those caused by a plutonic intrusive. In the former case the results are usually not very striking because of the way in which a lava stream surrounds itself with non-conducting scoriæ, and are such as may be referred to the action of dry heat. Bituminous coal is changed into a natural coke by the removal of its volatile constituents; clay may be baked into a hard red rock looking like earthenware, and limestone changed to quicklime by driving off carbonic acid gas. Plutonic intrusions are more efficient agents of change, because they are presumably of a higher temperature and retain their heat longer, and because the vapors and gases which they contain cannot escape into the atmosphere but strongly affect the invaded rocks. The rock invaded and metamorphosed may be either sedimentary, igneous, or already metamorphic, and the effects may be very marked or surprisingly small; indeed, it is often quite impossible to say why the changes should be so insignificant. The distance to which the zone of change extends is wider when the intrusive mass cuts across the strata than when it follows the bedding-plane, so that a dike or stock is more effective than a sill. Contact metamorphism, as its name implies, is a local phenomenon, but a widely ramifying and complex system of igneous intrusions may change large areas of sedimentary rocks.

"Regional or Dynamic Metamorphism applies to the reconstruction of rocks upon a great scale in areas covering, it may be, thousands of square miles, and evidently other processes in addition to those of contact metamorphism are needed to explain such widespread changes. Regionally metamorphic rocks are, with the exception of the slates, thoroly crystalline, and usually have lost all trace of whatever fossils and stratification planes they may originally have had.

"The first step in metamorphism consists in a mere hardening of the rock, accompanied with the loss of water and other volatile substances. In the second stage the component minerals already present are crystallized, but new compounds are sparingly formed. This stage is frequently accompanied by cleavage, which, to distinguish it from that of minerals, is often called slaty cleavage."

"Cleavage," suggests C. R. van Hise, "is a capacity present in some rocks to break in certain directions more easily than in others, while fissility is a structure in some rocks by virtue of which they are already separated into parallel laminæ in a state of nature. The term fissility thus complements cleavage, and the two are included under cleavage as ordinarily defined." Ordinary roofing slate is one of the best possible examples of a cleaved rock, and in beds of slate interstratified with other rocks the cleavage is usually quite perfect in the former, absent or but partially developed in the latter.

The causes of metamorphism have been summarized by W. R. Scott as follows:

"1. Heat is evidently a very important factor of change, as is shown by the phenomena of contact metamorphism and by numerous experiments by which the process has been imitated successfully. In contact metamorphism the heat is derived from the igneous magmas, and in dynamic it is in part mechanically generated, in part due to the interior heat of the earth invading deeply buried masses.

"2. Compression is believed to be the great agent of dynamic metamorphism, and the amount of the change depends upon the intensity of the compression and the depth at which it operates. Hence the varying results, ranging from gentle folding at one end of the series through violent folding to complete reconstruction, crystallization and foliation at the other.

"3. Moisture is another potent agent of reconstruction. Superheated water, under pressure, is able to attack and dissolve the most refractory substances and to build them up into new combinations. Many minerals, such as the felspars, which have never been artificially crystallized by dry heat alone, will crystallize readily in the presence of superheated water, and the water lowers the temperature necessary for metamorphism. Rocks which melt at 2,500° F. dry heat become pasty at 750° F. in the presence of water. In contact metamorphism steam is a very important factor of change, but other vapors and gases play an efficient part.

"4. Pressure, as distinguished from active compression, is a necessity for any extensive metamorphic action, whether contact or dynamic. It is the difference of pressure which is responsible for the different effects of surface flows of lava and of subterranean intrusions and which gives to depth its importance as a controlling factor. The dead-weight pressure of overlying rocks prevents the rapid escape of the mineralizing vapors, and when sufficiently great causes the rock to shear and flow without fracture. Limestone heated at the pressure of the atmosphere in a limekiln or an open vessel becomes quicklime through the expulsion of carbonic acid gas; but heated under pressure, so that the gas cannot escape, it crystallizes into marble. Such pressure also is an essential factor in dynamic metamorphism as a precondition in enabling the rock to behave more or less plastically under active compression and without shattering. Dynamic metamorphism must, therefore, take place at considerable depths below the surface."

The Non-foliated Rocks represent the less advanced stages of metamorphism, in which the forces of compression may have produced cleavage or fissility but not foliation.

The fissures, veins and faults which are to be found alike in Igneous, Sedimentary and Metamorphic rocks afford an excellent opportunity for the intrusion into the rock of matter of a dissimilar character. Thus waters bearing mineral compounds in solution, passing over such crevice or fissure, might readily precipitate that which it bears, each tiny grain of precipitated mineral forcing out water at the top. Sometimes these veins are filled in again with the same form of matter as that of which the main rock is composed, but different in structure; sometimes the veins are filled by sediment which has been blown or washed in, and not infrequently fissures caused by earthquakes have been filled up from below by the intrusion of alien substances forced up by the interior pressure.

Fissures thus filled vary greatly in dimensions, from a few inches to many miles in length. The minute veins are filled with material derived from the walls by solution and redeposited in the crevices, such as the veins of crystallized calcite in limestone. Great fissure veins, on the other hand, which may run unchanged for many miles, and penetrate to depths beyond the reach of mining, are "characterized," says Spurr, "by regular, straight walls, by a fairly constant width, and by a definite direction of both strike and dip."

A third class of mineral veins is composed of the veins of replacement, in which the circulating waters have not merely deposited minerals in an open fissure but have gradually substituted one substance for another by dissolving out the latter and replacing it with the former, it may be molecule by molecule, so that the replacing minerals are pseudomorphs after the older series. A replacement vein represents a water channel of some kind, and so it has a more or less definite direction, but it seldom has sharply defined walls, for the new deposits impregnate the country rock and fade away into it. Replacement veins are most commonly found in limestones, since those are the most readily soluble rocks, but they also occur in rocks which are relatively very insoluble, such as sandstones, and in igneous rocks like granite.

Frequently the ores of the commercially valuable metals are found in mineral veins, which then are called metalliferous veins.

"Structural geology," says W. B. Scott, in summarizing up the questions relative to the formation of the rocks, "brings vividly before one the innumerable changes through which the earth's surface has passed and which are recorded in the rocks. The sedimentary rocks, originally laid down under water in approximately horizontal positions, have been upheaved into land surfaces, either without losing that horizontality, or being tilted, folded, compressed, or even violently overturned. Or they may be fractured and dislocated in great faults and thrusts. These movements have been found to be due to enormous lateral compression set up within the crust of the earth, a compression generated in some manner not yet clearly understood. Whether folding or faulting shall result from a given compression depends upon the rigidity of the strata, upon the load which overlies them, and the sudden or gradual way in which compression is applied. The results of compression on a large scale are accompanied by certain minor changes not less characteristic. Compressed rocks are cleaved, fissile or schistose, according to the intensity of the action and whether the rocks affected are in the shell of flowage or of fracture. These changes may go so far as completely to reconstruct the minerals of the rocks, destroying the old, generating new, and obliterating the original character of the strata. Thus displacements, dislocations, cleavage, fissility and dynamic metamorphism are but the varying results of lateral compression acting under different conditions and at varying depths.

"Another class of rocks—the igneous, massive or unstratified—were found to have penetrated and overflowed the strata and to have consolidated in the fissures and cavities which they have made for themselves, or to have been poured out freely on the surface. According to the circumstances under which these masses have cooled the resulting rock is of glassy, porphyritic, finely or coarsely crystalline texture. When solidified as sheets or dikes the igneous rocks may be folded, faulted, cleaved or metamorphosed like the strata, and when a region has been long and repeatedly subjected to compression its structure may become excessively complex and the metamorphosis of its rocks so complete that not even the most careful examination will suffice to distinguish those rocks which were originally sedimentary from those which were igneous.

"Highly heated waters circulating through fissures and along the joint-planes of the rocks deposit the substances which form the mineral and metalliferous veins, tho concerning the source of these substances and of the solvent waters there is much difference of opinion. Our study has taught us that many of these processes go on deep within the earth's crust, and hence cannot be directly observed, but must be inferred from their results. Encouraging progress has already been made in this work, but very much more remains to be done before a knowledge of structure and its full meaning shall be even approximately complete."

CHAPTER XII

YOUR OWN NEIGHBORHOOD

AROUND every man spreads some horizon, either made by man or made by Nature, and this horizon is the alphabet of the book of his environment. The jagged carvings of the Bad Lands of Dakota, the unbroken circle of the prairies of Nevada, the deep clefts of the mountains of Tennessee, or the rounded slopes of the rolling country of Central New York—one has but to glance around each of these to read the first chapter of the story of the land on which the beholder stands.

There is a certain spell and homelikeness in the words "Your Own Neighborhood." It stands for something so familiar, often so well-loved. Sometimes, however, it stands for something too familiar, something to which we have grown too well accustomed, out of which we feel that we have sucked all the worth, into which we feel no new thing can ever come.

Nothing could be further from the truth. We have not read all the story, we simply have not known of the thousands of stories that our own neighborhood could tell. And, since every neighborhood has stories of its own to relate, it follows that in pointing them out, the writer can only give hints as to where they may be found. The dweller in that neighborhood shall find them out for himself.

"I will lift up mine eyes unto the hills, whence cometh my help," are words that might have been penned by a geologist. He lifts up his eyes to the hills, and, as he looks, out of the distant past come trooping the ghosts of mountain ranges long since dead, and of oceans filled with strange reptiles that no man ever saw alive—though their skeletons litter America. He sees some scratches on the surface of a boulder, and before him, as of old, the mighty glaciers of the Ice Age come crushing down, driving before them in headlong confusion a motley horde of mammoth and rhinoceros, cave-bear and sabre-tooth tiger. He sees, among these, the shrinking form of early man, and remembers how his bones have been found mixed with their bones in the great glacial deposits.

He stoops and picks up a pebble. It is a piece of flint, a compact form of quartz, and it brings before him all the other forms of quartz—the onyx, rock-crystal or the amethyst, and his mind goes back to the early days of the world when quartz was a-making. How small a difference in the story, then, would have made this common piece of flint an amethyst of great price!

Is the region in "Your Own Neighborhood" gently rolling, with hills with softly rounded crests? Then it is immeasurably old. You are a child of a region that has sunk into the sleep of quiet, and your neighborhood antedates by tens of millions of years the upstart neighborhoods of the far west. Do the little streams and rivers in your neighborhood flow with a shallow stream and a gentle current? Theirs, too, is the quiet of age. Suppose, however, they run with deeper banks and swifter streams; suppose, even, they have a sort of canyon through which they flow; then you may know that they are not underlaid by the granite of an older time, but by some sedimentary rock that not so long ago was the bed of a ghost-like ocean where monstrous reptiles sprawled.

Is "Your Own Neighborhood" in New England? Then read the story of the granite, the gray, gaunt ancestor of rocks, and see if there is not pride in its sturdy defiance of the ravages of time, when the rocks of yesterday—the sandstones—as in the Garden of the Gods, in Colorado, are melting away like snow under the summer sun.

Is "Your Own Neighborhood" in the Catskills? Look at their long, flowing lines, the valleys that lie so snugly embosomed among them, and you will feel the spell of quiet and of rest. Hills of erosion, these, worn down to roundness by the hand of time. Your home, whether on the hillside or in the valley, lies at least two thousand feet below the original surface of a tableland, which, in Devonian times, stretched an unbroken expanse at least as high above the highest points of the Catskills as that point to-day is above the level of the sea. But, if you like to read the story, the topography of your own neighborhood will go back farther still, and show you, bit by bit, what happened in the days before even that Devonian tableland was built.

Is "Your Own Neighborhood" in the northern middle states? Then is the movement of the Ice Age part of your story. It is not so long ago—as the geologist counts time—that all the northern middle states were in the state condition as Greenland is today. The great Polar Ice-cap ran along a line stretching (approximately) from Trenton, N. J., to St. Louis, and thence to Omaha and the Yellowstone. In more recent times still, great glaciers flowed over the regions which are now the heart of America's dairying industry. The glaciers are not all gone; Mount Rainier, Wash., has some still; Glacier National Park has a number of them.

Is "Your Own Neighborhood" in any part of the great Appalachian chain? Very different is its story. These mountains are made of rocks laid down at the bottom of the sea in Paleozoic time. Twenty-five thousand feet were laid down under the water, and then, in a convulsion of the earth, the crust was squeezed and the mountain range thrust forth. What were the rocks laid down under the sea? What were the creatures living in that sea? If you would read that story, it lies around you in a thousand stones and boulders, sandstones and limestones, organic and inorganic rocks, ready to reveal the tale to anyone who takes the trouble to turn the pages.

Is "Your Own Neighborhood" in the alluvial plains of the South? Think of the Mississippi valley and of the great rivers of the past. Look at the soil of the "black belt" or the "red earth" of Georgia. There the book is not only written in plain type, but brilliantly colored. And, if you would see how the world is always being made anew, see how each year the Mississippi is carrying the soil from Ohio and the other states within its basin, and, of that mud, making at its delta a new land that juts far out into the Gulf of Mexico. In course of time it may fill the Gulf, and the West Indies may be a range of hills around a great fertile plain. The region will pass through the swamp stage first, like the Everglades of Florida, which are midway on their passage from sea to land.

Is "Your Own Neighborhood" on the plains? Or in the Rocky Mountains? Or in the Sierras? Then the story hardly needs to be pointed out, it is so simply told. For these are the "newly rich" of geologic time. They are more recent than the Alps, than the Himalayas, which also—like the Appalachians—were nursed in the cradle of the Tertiary Seas. Frail creatures, too, these western mountains, soft and friable. They are still rising, slowly, but they wear away even faster. The old rocks abide longer. The Cretaceous or chalk formations, the limestones, speedily melt away. See how limestone-underlaid Kentucky is undermined with caves!

Suppose we take the earth as 365 millions years old, and consider this period as a year, one million years being taken as a day. Then the Appalachians were raised in September, the Sierra Nevada toward the end of October, the Rocky Mountains during December. On such a scale the whole period of Man is not likely to have been further back than the evening of December 31st, the earliest historic evidence (in Egypt) is not more than ten minutes before the last midnight, and it is, in comparison with the years of the world's age, less than five minutes' interval between our own times and the days of Moses.

Nor is it to be supposed that the phrase "Your Own Neighborhood" necessarily implies in geology a section as large as New England. It may be as large or as small as one wishes. Pick up a piece of rock from New York City and a piece from Hoboken, just across the Hudson River. New York shore is tens of millions of years the older; the rock you have picked up is part of the old Archæan rock-bottom of the world. On the Jersey shore the famous Palisades are Triassic, between the Appalachian and the Sierras, or, using our former time scale, in the end of September or the beginning of October of that vast Earth-Year. The New York rock antedates the first life upon this planet, the Jersey rock is marked with impressions of the feet of the giant reptiles. Take even so small a piece of land as Staten Island. Here, within a space of ten miles, is land that was once under the ice-cap; land strewn with the boulders of the moraine, scratched and marred; and land that the ice never reached. One part of the Atlantic coast shows where the sea is creeping in, another where the land is creeping out. In other places are old forests now under a lake bed, elsewhere are lake beaches hundreds of feet above the water. This farm lies on clay, the next on gravel, the third on shale. Each has a different story.

Take an ordinary claw-hammer and crack the first dozen stones you find near your house. This one is granite, and tells its tale of fire. You see in it the quartz, felspar and the mica. If you could break the crystals of quartz, you would find them cleave like glass, but if you try to break the mica it will divide into leaves like the thinnest tissue paper, but flexible and elastic. The little crystals of felspar, too, from the decomposition of these comes kaolin or the china-clay, from which fine china is made. All these stories in a granite pebble! And still nothing has been said of all kinds of granite, all the colorings, gray, green, pink and red. Yet every tint is a clue to a further story still.

Your next stone may be a piece of chalk. Look at this closely and you shall see the sea shells of which it is made, for chalk is but the cemetery of untold billions of tiny sea creatures whose shells, after they died, sank to the ocean floor. Besides this may be found a piece of slate, which is a rock made of clay, hardened by compression. There are dozens of different kinds of slates. Like the sandstones, the slates are composed of an endless variety of other rocks, and in them, also particles of quartz and scales of mica may be seen.

Every neighborhood has its own rocks and pebbles, and these tell a story fully as wonderful as the vaster book of the scenery of hill and valley. Cut these pebbles into thin slices, examine them under a microscope—a scientific study within the means of every one—and a new world opens. Here is a story that the world so far has only partly read. It is a fascinating study, which may be carried on in a city apartment, a suburban home or a farmhouse kitchen as readily as in a well-equipped geo-physical laboratory. If to this be added simple experiments on crystallization, the field of wonder grows to the point of entrancement.

This study of one's own neighborhood, or physiography, is becoming an important branch of Geology. It has been suggested that this subject treated from the geological side should be called Geomorphogeny, since the geologist makes use of the topography to determine the nature of the changes, while the physical geographer employs the conception of changes to explain the topography. It will be seen immediately how the two subjects interlock, but none the less there is a quite different principle involved.

The questions involved in Geomorphogeny, then, are those of aggradation, of the elevation of the land, and diastrophism, the removal of land in one place for the purpose of building it up in another. A third class of factors, which, however, are passive rather than active, are the character, arrangement and attitude of the rock masses. A partially degraded region in which the rocks are homogeneous will have a very different kind of relief from one in which the rocks are heterogeneous and differ materially in their powers of resistance to the denuding agents.

The topography of any region is the resultant of the very complex interaction of many different kinds of factors and is subject to continual change according to definite laws. Suppose, in the first instance, a region newly upheaved from beneath the sea into dry land. The topography of such an area will be constructional, due entirely to the processes of diastrophism and accumulation and characterized by the absence of a highly developed system of drainage by streams. The coastal plain of the middle and southern Atlantic States is an example of such topography but slightly modified

Next, the processes of denudation begin their work upon the region. The sea attacks the coast-line by cutting it back in one place and building it out in another until a condition of equilibrium is attained. Rivers are established, adjusting themselves to the structure of the underlying rocks and cutting deep, trench-like valleys, while the atmospheric agencies widen out the valleys, slowly wearing down and washing away the sides and tops of the hills.

A river has its stages of development, youth, maturity and old age, just as has a land surface, each stage displaying its characteristic marks. In a newly upheaved or newly folded land the streams are determined entirely by the slopes of the new surface and are called consequent streams. As the river system becomes somewhat older, the stream channels are deepened, the larger ones being cut down to base-level, and if the region be one of considerable elevation, deep gorges and cañons are excavated. A mature river system is characterized by the complete development of its tributaries and drainage, so that every part of its basin is reached by the ramifying channels. Valley floors are broadened and deposition begins upon them, and the streams, reaching a condition of equilibrium between erosion and deposition, are said to be graded.

The final stages of river development are reached when the base-level is attained and the drainage basin reduced to a peneplain by the combined action of the streams and weathering.

As a river system approaches maturity it will increase the number of its branches, and those branches which were not at all represented in the youthful stages of the system and are opened out along lines of yielding rocks are called subsequent.

However the streams of a district may have been established in the first instance, whether they were consequent, antecedent or superimposed, they are liable to changes more or less profound and far-reaching. The up-stream extension of branches and the shifting of divides result in the capture of streams, or parts of such, by others more favorably situated, one master stream gradually absorbing many smaller ones which had originally been independent.

Coast-lines also are of great physiographic importance. There is no greater mistake than to suppose the seacoast to be merely a line whereat the sea now washes. Yet it would be easy to find many people who would define the seacoast as being that stretch of land between high-water and low-water mark, with perhaps the addition of the former beach (in some cases), to the point of the beginning of land vegetation. Yet the coast line, truly speaking, may extend a long distance under the sea, and in similar wise a wide range of marine beach formation may exist on land, even miles away from the sea.

"Regular coasts," says A. Penck, "continue for great distances without notable indentations and, for the most part, in gentle curves, convex toward the land, which are connected by curved lines or meet at obtuse angles. The flatter the coast, the more perfectly is this type developed, and the coast line runs for many kilometers in the same curve. With a steep slope the course is regular only in general; in detail it seems as tho drawn by a trembling hand, with numerous little prominences, which project but a few hundred meters beyond the general coast line and separated from one another by shallow, curved indentations."

The most conspicuous example of the irregular coast unquestionably is the fjord, seen in Norway and Scotland. They are irregular to a wonderful degree, possessing only this in common that they are produced by the depression and submergence of land surfaces, not by the throwing up of the high bluff, cliffs and crags that remain. The fjords are long, narrow, frequently branched and usually very deep.

The ridges of land which separate adjoining fjords are frequently notched by low passes, which seaward become straits, connecting the fjords and cutting up the ridges into islands, which are always very numerous along coasts of this class. The famous "inside passage" from Puget Sound to Sitka, Alaska, is a network of deep waterways among countless islands. What are termed Rias Coasts have frequently been regarded as fjord coasts, but the bays here are shorter, more funnel-shaped and not nearly so deep as fjords. Moreover, they are not of glacial origin and hence are more widely distributed.

Calas Coasts are marked by numerous short, semi-circular and rather shallow bays, separated by narrow peninsulas and owe their irregularities not to wave erosion, but to the submergence of land valleys; those of the typical kind are due to the depression of mountain slopes, furrowed by numerous short ravines.

Faults are probably the cause of deep lobate coasts, such as are to be found in Greece and in Hayti and Japan. There the bays are not so much irregularities in the coast line as deep gulfs, which have taken into themselves hundreds of square miles of land surface and where the interlocking gulfs are of the same order of magnitude.

The popular use of the word "mountain" is another snare. For example, there are many so-called mountains which are nothing more than the tops of the original plain, the whole of the surrounding country having sunk. A well-known example of this is the Grand Cañon of the Colorado, where, altho there are cliffs and buttes of immense height from their bases, yet a line from side to side of the great gorge will reveal that none are greatly higher than the surface of the plain from which the river has cut itself down. Some so-called mountain peaks and ridges are merely the portions of dissected plateaus left standing, such as Lookout Mountain and Missionary Ridge in Tennessee and the Alleghany Front in Pennsylvania.

A mountain range is made up of a series of more or less parallel ridges, all of which were formed within a single geosyncline or on its borders. The Appalachian range, the Wasatch, the Coast Range are examples of typical mountain ranges. A mountain system is made up of a number of parallel or consecutive ranges, formed in separate geosynclines, but of approximately similar dates of upheaval. The Appalachian system comprises the Appalachian range, running from New York to Georgia; the Acadian range in Nova Scotia and New Brunswick, and the Ouachita range in Arkansas. Each of these ranges was formed in a different geosynclinal, but at the same geological date, and they are consecutive, having a common direction. A mountain chain comprises two or more systems in the same general region of elevation, but of different dates of origin. The Appalachian chain includes the Appalachian system, the Blue Ridge, the Highlands of New Jersey and the Hudson, a system of different date, and the Taconic system of western New England, which was not formed at the same time as either of the others. A cordillera consists of several mountain chains in the same part of the continent. Thus the chains of the Rocky Mountains, Sierra Nevada, Coast Range and their prolongations in Canada together make up the Rocky Mountain or Western Cordillera. From these definitions it will appear that the mountain range has a unity of structure and origin which fits it especially for study. If the history of the ranges be understood, the systems and chains will offer little additional difficulty.

The manner in which mountain ranges have been formed must be deduced from a careful study of their structure, for no one has ever witnessed the process of that formation. Mountain building may be going on at the present time; indeed, there is no reason to suppose that it is not, but so slowly is the work carried on that it withdraws itself entirely from observation. Nevertheless the general course of events may be inferred with much confidence from the structure of the range.

The first step in the formation of a mountain range must evidently be the accumulation of an immensely thick body of strata. This, of course, must have taken place chiefly under shoal water, as thick strata can be accumulated only in rather shallow water and parallel with shore lines. To accumulate thick strata in shoal water, the bottom must subside as the sediments are piled upon it, else the water would be filled up and deposition cease. Such a sinking trough is a geosyncline, and in geosynclines filled with sediments is the cradle of the mountains.

The second stage in the building of a range is the upheaval of the thick mass of strata into a series of folds. This can be produced only by lateral compression, a conclusion which is sustained not only by the mechanics of folding and faulting, but also by the less obvious structures, such as cleavage and fissility, metamorphism, the microscopic crumplings and plications and the crushing and flowage of the mineral particles. The compressing force does not raise anticlines with great cavities beneath them, for such arches could not well be self-supporting, but mashes together the whole mass of strata, raising them into folds and wrinkles, crowding the beds into a greatly reduced breadth; or, when they are not sufficiently loaded to be plastic, breaking and dislocating them in great thrusts. It is not necessary to suppose that a mountain range was thrown up by one steady movement. On the contrary, there is good reason to believe that repeated movements, separated, it may be, by long intervals of time, have been engaged in the work.

There are certain mountain ranges which have a different structure and must have had a correspondingly different mode of origin. As already pointed out, in the Great Basin, which lies between the Sierra

Nevada and the Wasatch Mountains, are a number of parallel mountain ranges with a prevalent north and south trend, which are collectively called the Basin Ranges. These mountains are not folds of very thick strata, but tilted-fault blocks, which have been made by normal faults, each upthrow side standing as a great escarpment, but with a tilted top that gradually slopes back to the foot of the next block, to which it stands as the downthrow side. The processes of denudation have carved these tilted blocks into peaks and ridges of the ordinary kind. Every mountain range has been profoundly affected by the agencies of denudation, and their ridges and peaks, their cliffs and valleys have been carved out of swelling folds and domes or angular, tilted fault-blocks.

"The general character of the structure of the American continent is extreme simplicity," says Geikie, "as compared with that of the Old World. In part of the Rocky Mountain region, for example, while the Paleozoic formations lie unconformably upon pre-Cambrian gneiss, there is, according to King, a regular conformable sequence from the lowest Paleozoic to the Jurassic rocks, tho probably many local unconformabilities exist. During the enormous interval of time represented by these massive formations, what is now the present axis of the continent appears to have been exempt from any great orogenic paroxysm and to have remained hardly disturbed by more than a gentle and protracted subsidence.

"In the great depression or geosyncline thus produced all the Paleozoic and a great part of the Mesozoic rocks were accumulated. At the close of the Jurassic Period the first great upheavals took place. Two lofty ranges of mountains—the Sierra Nevada (now with summits more than 14,000 feet high) and the Wasatch—400 miles miles apart, were pushed up from the great subsiding area. These movements were followed by a prolonged subsidence, during which Cretaceous sediments accumulated over the Rocky Mountain region to a depth of 9,000 feet or more. Then came another vast uplift, whereby the Cretaceous sediments were elevated into the crests of the mountains, and a parallel coast range was formed fronting the Pacific.

"Intense metamorphism of the Cretaceous rocks is stated to have taken place. The Rocky Mountains, with the elevated table land from which they rise, now permanently raised above the sea, were gradually elevated to their present height. Vast lakes filled depressions among them, in which, and on the plains in front of the mountains, as in the Tertiary basins of the Alps and the Gondwana series of the Himalaya, enormous masses of sediment accumulated. The slopes of the land were clothed with an abundant vegetation, in which we may trace the ancestors of many of the living trees of North America. One of the most striking features in the later phases of this history was the outpouring of great floods of trachyte, basalt and other lavas from many points and fissures over a vast space of the Rocky Mountains and the tracts lying to the west. In the Snake River region alone the basalts have a depth of 700 to 1,000 feet over an area 300 miles in breadth."

CHAPTER XIII

READING THE LIFE OF THE PAST

WHILE the life-history of organisms is truly biology and the life-history of extinct forms of animals belongs largely to paleontology, yet the geologist has an intimate relation to both—to the life-history of present organisms because of their effects upon the earth's surface and to the relics of past organic life because their presence in certain rocks reveals the conditions that prevailed when those rocks were laid down.

"Historical geology," says Geikie, "deals with fossils or organic remains preserved in natural deposits and endeavors to gather from them information as to the history of the globe and its inhabitants. The term fossil, meaning literally anything 'dug up,' was formerly applied indiscriminately to any mineral substance taken out of the earth's crust, whether organized or not. Ordinary minerals and rocks were thus included as fossils.

"For many years, however, the meaning of the word has been so restricted as to include only the remains of traces of plants and animals preserved in any natural formation, whether hard rock or loose superficial deposit. The idea of antiquity or relative date is not necessarily involved in this conception of the term. Thus the bones of a sheep buried under gravel and slit by a modern flood and the obscure crystalline traces of a coral in ancient masses of limestone are equally fossils.

"Nor has the term fossil any limitation as to organic grade. It includes not merely the remains of organisms, but also whatever was directly connected with or produced by these organisms. Thus the resin which exuded from trees of long-perished forests is as much a fossil as any portion of the stem, leaves, flowers or fruit, and in some respects is even more valuable to the geologist than more determinable remains of its parent trees, because it has often preserved in admirable perfection the insects which flitted about in the woodlands. The burrows or trails of a worm, in sandstone or shale, claim recognition as fossils, and indeed are commonly the only indications to be met with of the existence of annelid life among old geological formations. The droppings (coprolites) of fishes and reptiles are excellent fossils, and tell their tale as to the presence and food of vertebrate life in ancient waters. The little agglutinated cases of the caddis-worm remain as fossils in formations from which perchance most other traces of life may have passed away. Nay, the very handiwork of man, when preserved in any natural manner, is entitled to rank among fossils, as where his flint implements have been dropped into the prehistoric gravels of river-valleys or where his canoes have been buried in the silt of lake-bottoms.

"The term fossil, moreover, suffers no restriction as to the condition or state of preservation of any organism. In some rare instances the very flesh, skin and hair of a mammal have been preserved for thousands of years, as in the case of mammoth carcasses entombed in the frozen mud-cliffs of Siberia. Generally, all or most of the original animal matter has disappeared and the organism has been more or less completely mineralized or petrified. It often happens that the whole organism has decayed and a mere cast in amorphous mineral matter, as sand, clay, ironstone, silica or limestone, remains; yet all these variations must be comprised in the comprehensive term fossil."

"The conditions of the preservation of fossils," says Scott, "are much more favorable to some kinds of organisms than to others. It is only under the rarest circumstances that soft, gelatinous animals, which (like jelly-fish) have no hard parts, can leave traces in the rocks. The vast majority of fossilized animals are those which have hard shells, scales, teeth or bones; and of plants, those which contain a sufficient amount of woody tissue. Again, the conditions under which organisms live have a great influence upon the chances of their preservation as fossils. Land animals and plants are much less favorably situated than are aquatic forms, and since the greater number of sedimentary rocks were laid down in the sea marine organisms are much more common as fossils than are those of fresh water.

"On land fossils have been preserved, sometimes in astonishing numbers, under wind-made accumulations of sand, dust or volcanic ash and in the flood-plain deposits of rivers. Peat bogs are excellent places for the fossilization, and the coal seams have yielded great numbers of fossils, principally of plants. The remains of land animals and plants, especially of the latter, are sometimes swept out to sea, sink to the bottom and are there covered up and preserved in the deposits; but such occurrences are relatively uncommon. Small lakes offer more favorable conditions for the preservation of terrestrial organisms. Surrounding trees drop their leaves, flowers and fruit upon the mud-flats, insects fall into the quiet waters, while quadrupeds are mired in mud or quicksand and soon buried out of sight. Flooded streams bring in quantities of vegetable débris, together with the carcasses of land animals drowned by the sudden rise of the flood.

"The great series of fresh-water and volcanic-ash deposits, which for long ages were formed in various parts of our West, have proved to be a marvelous museum of the land and fresh-water life of that region. On the fine-grained shales are preserved innumerable insects and fishes, with multitudes of leaves, many fruits and occasionally flowers, while in the sands, clays and tuffs are entombed the bones of the reptiles, mammals and, more rarely, birds of the land mingled with those of the crocodiles, turtles and fishes that lived in the water. Similar deposits are known in other continents. But it is on the sea-bed that the conditions are most favorable to the preservation of the greatest number and variety of fossils. Among the littoral deposits ground by the ceaseless action of the surf fossils are not likely to be abundant or well preserved, but in quieter and deeper waters vast numbers of dead shells and the like accumulate and are buried in sediments."

"A geological chronology," says Scott again, "is constructed by carefully determining, first of all, the order of superposition of the stratified rocks and next by learning the fossils characteristic of each group of strata. To many it has seemed that this is reasoning in a circle, but that is because the argument is not fully stated, some of its steps being omitted. The order of succession among the fossils is determined from the order of superposition of the strata in which they occur. When that succession has been thus established it may be employed as a general standard.

"Great physical events, such as the upheaval of mountain ranges, widespread transgressions of the sea and changes of climate, often provide a means of correlating the strata of different continents with greater precision than can be done with the aid of fossils only. The latter are, however, indispensable means of first determining which of these events are comparable in different regions. The history is recorded partly in the nature and structure of the rocks, partly in the fossils and partly in the topographical forms of the land and the courses of the streams. By combining these different lines of evidence, local histories are constructed for each region, until from these the story of the whole continent may be compiled. The comparative study of the fossils then gives the clue for uniting the history of the different continents into the history of the earth.

"The method of making the divisions and subdivisions of geological time is not yet a fixed one, and there is much difference in the usage of various writers. The names of the divisions also have been given at various times and in many lands, according to no particular system. Most of these names have been taken from the locality or district where the rocks in question were first studied or are most typically displayed, as Devonian from Devonshire, Jurassic from the Jura Mountains. Some are named from a characteristic or prevalent kind of rock, such as Cretaceous (Latin 'creta,' chalk) and Carboniferous.

Of late there has been a tendency toward a more uniform method of nomenclature, and to the use of one set of terms for the divisions of time and another and corresponding set for the divisions of the strata. The following table represents the divisions in the scale of time and the scale of rocks which have been adopted by the International Geological Congress:

TIME SCALE	ROCK SCALE
Era	Group
Period	System
Epoch	Series
Age	Stage
	Substage
	Zone

"It will be observed that the subdivision is carried farther in the scale of rocks than in that of time, because of the generally local character of these minor subdivisions. The names employed are, as yet, the same for both scales, and we speak of the Paleozoic Era or Group and of the Silurian Period or System. It has been proposed to give separate names to the divisions of the two scales, and this would be an improvement in some respects.

TABLE OF MAJOR GEOLOGICAL DIVISIONS

Cenozoic Era	Quaternary Period
	Tertiary Period
Mesozoic Era	Cretaceous Period
	Jurassic Period
	Triassic Period
Paleozoic Era	Permian Period
	Carboniferous Period
	Devonian Period
	Silurian Period
	Ordovician Period
	Cambrian Period
Pre-Cambrian Eras	Algonkian Period
	Archæan Period

"Tracing the history of mankind back to very ancient times, records become more and more scanty and less intelligible, until history fades into myth and tradition. Of a still earlier age there is not even a tradition; it is prehistoric. Similarly among the geological records the earliest are in a state of such excessive confusion that they are exceedingly difficult to understand, and between different observers there are radical differences of opinion both as to the facts and as to their interpretation. Furthermore, they must have been an inconceivably long time earlier than the most ancient recorded periods, as to which conjecture and inference are the only resource. In these difficult straits astronomy offers valuable assistance to the baffled geologist. The Nebular Hypothesis is a scheme of the development of the solar system which is generally accepted by astronomers in some form as essentially true.

"The term nebular hypothesis is usually, tho not with exactness, limited to one particular form, according to which the place of the present solar system was originally occupied by a vast rotating nebula, a mass of intensely heated vapor, or possibly clouds of meteorites, extending beyond the orbit of the outermost planet. As the nebula cooled by radiation, it contracted, leaving behind it successive rings, like those of the planet Saturn, but on a vastly larger scale. The rings kept up the rotation imparted by the nebula and all of them lay in nearly the same plane. Unequal contraction in various parts of each revolving ring caused it to break up and gather by mutual attraction into masses. If these rings were composed of relatively small solid masses, like meteorites, or if they had solidified by condensation of the vapors, the heat generated by the collision, as the broken ring was gathered into a mass, would suffice to raise the temperature and liquefy or vaporize the mass. By revolution the nebulous masses would assume a spheroidal shape and become planets. The central mass of the original nebula forms the sun, which is still in an intensely heated, incandescent state."

Another form of the nebular hypothesis, called for the sake of distinction the Planetesimal Hypothesis, has recently been proposed by Professor Chamberlin. This postulates, as the beginning of the solar system, a spiral nebula, "and that the matter of this parent nebula was in a finely divided solid or liquid state before aggregation. . . . It regards the knots of the nebula as the nuclei of the future planets and the nebulous haze as matter to be added to these nuclei to form the planets. It assumes that both the knots and the particles of the nebulous haze moved about the central mass in elliptical orbits of considerable but not excessive eccentricity. . . . It deduces a relatively slow growth of the earth, with a rising internal temperature developed in the central parts and creeping outward."

From the strictly geological standpoint the most important difference between the Nebular and the Planetesimal Hypotheses is that, according to the former, the earth has passed through a gaseous and a molten stage and therefore must have formed a crust by solidification, while the latter leads to the conclusion that the earth has been solid from the beginning, and consequently never formed a crust of solidification.

"It is unfortunate," says W. B. Scott in his "Introduction to Geology" (Macmillan Co.), "that an account of historical geology should begin with the most difficult and obscure part of the subject, but the treatment must be in accordance with the chronological order, and the oldest rocks are the least intelligible. The ordinary criteria of the historical method—namely, the stratigraphical succession and the comparison of fossils—fail us here almost entirely, and the only way of correlating the rocks of different regions and continents is by means of the characters of the rocks themselves. In the present state of knowledge 'lithological similarity' is not a safe guide. So many metamorphic rocks, once referred to the Archæan, have proved to be of much later date, that some cautious geologists, who have no confidence in 'lithological similarities,' prefer not to use the term Archæan at all, but to employ local terms for the oldest crystalline rocks exposed in a given district. The Archæan includes the most ancient rocks, often spoken of as the 'basement, or basal complex.' Its antiquity is best assured in regions where it is separated by thick series of sedimentary or metamorphic rocks from the Lower Cambrian, which can be certainly identified by its fossils."

The Archæan is composed of completely crystalline rocks of various types. Massive rocks, such as granite and basic eruptives, and foliated rocks, like gneissoid granite, gneiss, many varieties of schists, are intermingled in the most intricate way, a characteristic well expressed in the oft-used phrase of the basal or fundamental complex for the Archæan. The component mineral particles show plainly the intense dynamic metamorphism to which they have been subjected in their extremely complex arrangement and in their laminated and crushed condition. The rocks thus referred to the Archæan are not necessarily all of the same age, but they are all of vast antiquity and older than any other known series. They are of very great but unknown thickness, for the bottom of them is nowhere to be seen, and even when thrown up into mountain ranges, erosion has in no case cut so deeply into these rocks as to expose anything different below them.

"The origin of the Archæan Rocks," Scott resumes, "is a problem which has given rise to a great deal of discussion, but a solution appears to be near. Independently, in many countries, observers have reached the conclusion that these rocks are divisible into two great series, a schist series composed chiefly of highly metamorphosed sedimentary and volcanic rocks, and a gneissoid granite series, which is intrusive and later than the former.

"Assuming that this conclusion is true, at least as a working hypothesis, it involves certain curious consequences. Surface lava flows and volcanic tuffs, and still more sedimentary rocks, necessarily imply a solid floor upon which they were laid down, but of this floor not a trace has anywhere been found. The question immediately arises, What has become of it? No answer to this question can yet be given, but apparently the most likely suggestion is that the ascending floods of molten magma, which gave rise to the gneissoid granites, must have melted and assimilated it. If this were only a local phenomenon, there would be nothing very surprising about it, but it would seem to be true of the entire globe, and this is a startling conclusion. It would appear, then, that a solid crust, however formed, was for a very long time sufficiently rigid and stable to allow a great thickness of sedimentary and volcanic rocks to be accumulated upon it and then was engulfed and destroyed by a universally ascending magma, though it is not necessary to suppose that this took place simultaneously over the whole earth or even within a relatively short period of time; it may have required ages in the accomplishment. Furthermore, it must not be forgotten that remnants of the floor may yet be discovered in little-known regions. If this complete and universal assimilation actually took place, it is an absolutely unique phenomenon in the recorded history of the earth, though something more or less similar may have happened many times before that record began."

The present writer is not entirely in agreement with Professor Scott as to the following division of geologic time, but in view of the fact that the sequence used in this summary is taken from his "Introduction to Geology," no change will be made in the order of presentation.

"The Algonkian is the name proposed by the United States Geological Survey for the great series of sedimentary and metamorphic rocks which lie between the basal Archæan complex and the oldest Paleozoic strata; it is but little used outside of this country and is not universally employed even here, but it is beginning to make its way in Europe and serves a useful, though possibly a temporary, purpose. While it is possible, though not very likely, that more advanced knowledge may make it possible to distribute these rocks partly into the Archæan and partly into the Paleozoic, yet for the present, at least, it is better to form a separate grand division for them.

"The Algonkian rocks, which are widely distributed in North America, form an immensely thick mass of strata and of metamorphic rocks which are believed to represent those strata in other regions. These metamorphic rocks were long generally referred to as the Huronians, which was regarded as the upper portion of the Archæan, but, so far as can be learned, they occupy the same stratigraphical position as certain little changed sediments, between the fundamental complex below and the Cambrian above. At the base of the magnificent section exposed in the Grand Cañon of the Colorado is a very thick mass of strata, separated by great unconformities from the Archæan gneiss below and from the overlying Cambrian. This mass is again subdivided by minor unconformities into three series. The lower series, at least 1,000 feet thick, and perhaps more, is made up of stratified quartzites and semi-crystalline schists, cut by intrusive granite. Above this come nearly 7,000 feet of sandstones, with included lava sheets, and at the top more than 5,000 feet of shales and limestones, in which a few fossils have been found. The two upper series are not at all metamorphic. All these strata are steeply inclined and upon their truncated edges rests the sandstone referred by Mr. Walcott to the Middle Cambrian."

In the Grand Cañon and Montana determinable fossils have been found in the less changed sediments, but they are too few and scanty to indicate much of the life of the times. Evidences of life are not wanting in the metamorphic rocks of the eastern and northern regions, but they are indirect. The strata of crystallized limestone are indications of the presence of animal life in the Algonkian seas. The great quantities of graphite diffused through many of the schists and the beds of iron ore likewise tend to show the existence of plants at the same time. More conclusive are the determinable fossils obtained in the Belt series of Montana and in the Grand Cañon series, which include the tracks of worms, brachiopods and fragments of large Crustacea referable to the Eurypterida. Such remains imply a long antecedent history of life, the records of which remain to be discovered.

With regard to the comparative value of the pre-Cambrian rocks in the chronology of geological history no precise statement can be made, but various circumstances show that they must represent an enormous period of time. From the general character of the Cambrian fauna it must be regarded as certain that life had existed on the earth for a long series of ages before that fauna appeared, in order that such well-advanced grades of organization should then have been reached. One of the most interesting chapters of geological history would be supplied if some adequate account could be given of the stages of this long pre-Cambrian evolution.

"The Paleozoic is the oldest of the three main groups into which the normal fossiliferous strata are divided," continues Scott. "It forms the first legible volume of the earth's history, and in interpreting it speculation and hypothesis play a much less prominent part than in the pre-Cambrian volume. The Paleozoic rocks are conglomerates, sandstones, shales and limestones, with quite extensive areas of metamorphic rocks, and associated igneous masses, both volcanic and plutonic. The thickness of these rocks is very great, estimated in Europe at a maximum of 100,000 feet. This does not imply that such a thickness is found in any one place, but that if the maximum thickness of each of the subordinate divisions be added together, they will amount to that sum.

"In this country more than 25,000 feet of Paleozoic strata are exposed in the much-folded and profoundly denuded Appalachian Mountains, but in the Mississippi valley they attain only a fraction of that thickness. These rocks are, in the vast majority of cases, of marine origin, but some fresh-water beds are known, and very extensive swamp and river deposits have preserved a record of much of the land life of the era, especially of its later portions. That there must have been land-surfaces is abundantly shown by the immense thickness and extent of the strata, all of which were derived from the waste of the land. Both in Europe and in North America the land areas were prevailing toward the north and are doubtless indicated, in part, by the great regions of the pre-Cambrian metamorphic rocks.

"The general character of the Paleozoic beds shows that they were, in large measure, laid down in shallow water in the neighborhood of land. Their great thickness indicates further the enormous denudation which the land areas underwent. The calculation has not been made for this country, but for Great Britain; Geikie states that the lower half of the Paleozoic group represents the waste of a plateau larger than Spain and 5,000 feet high, cut down to base level. Very widespread disturbances of the earth's crust before the beginning of the Paleozoic era and at its close have produced well-nigh universal uncomformities with both the underlying pre-Cambrian and the overlying Mesozoic rocks; at only a few points are transitional series found.

"Early in Paleozoic time were established the main geographical outlines which dominated the growth of the North American continent, a growth which was for the most part steady and tranquil. These conditions may be briefly stated as the formation of a great interior continental sea, divided from the Atlantic and the Pacific by more or less extensive and variable land areas. There are thus three principal regions of continental development: those of the Atlantic and Pacific borders and the interior. In addition, the eastern border is subdivided by pre-Cambrian ridges into subordinate areas of deposition. At the present time the surface rocks over the eastern half of the continent are prevailingly Paleozoic, extending chiefly southward and southeastward from the great pre-Cambrian mass of the north. Paleozoic time was of vast length, perhaps exceeding that of the combined Mesozoic and Cenozoic eras.

"The subdivisions of the Paleozoic are very clearly marked, locally often by unconformities, but on a wide scale by the changes in the character of the fossils.

"Paleozoic life possesses an individuality not less distinctly marked than that of the group of strata, which demarcates it very sharply from the life of succeeding periods and gives a certain unity of character to the successive assemblages of plants (floras) and of animals (faunas). The era is remarkable both for what it possesses and what it lacks. Among plants the vegetation is made up principally of Cryptogams, seaweeds, ferns, club-mosses and horsetails. Especially characteristic are the gigantic tree-like club-mosses and horsetails, which are now represented only by very small herbaceous forms. The only flowering plants known are the Gymnosperms, the Cycads and their allies; no Angiosperms have been discovered. Paleozoic forests must have been singularly gloomy and monotonous, lacking entirely the bright flowers and changing foliage of later periods.

"The Paleozoic fauna is largely made up of marine invertebrates, in the early periods entirely so—*i.e.*, so far as we have yet learned, though land life surely began before the oldest records of it yet discovered. Graptolites and Hydroid Corals, true Corals, Echinoderms (especially Crinoids, Cystideans and Blastoids), long-hinged and hingeless Brachiopods, Mollusca (particularly the Nautiloid Cephalopods) and the crustacean groups of Trilobites and Eurypterida are the most abundant and characteristic types of animal life. Insects, centipedes and spiders were common toward the end of the era. Cambrian rocks contain no fossil vertebrates, but they make their appearance in the Ordovician. For long ages the only vertebrates were fishes and certain low types allied to the fishes, but at the end of the Devonian and in the Carboniferous appeared the Amphibia, followed in the Permian by true Reptiles. Teleosts, such as make up by far the largest part of the modern fish-fauna, both marine and fresh-water, as well as birds and mammals, are entirely absent from the Paleozoic.

"The overwhelming majority of Paleozoic species, and even genera, fail to pass over into the Mesozoic, and even in the larger groups which continued to flourish almost always a more or less complete change of structure occurs, so that Paleozoic corals, Echinoderms and fishes, for example, are very markedly distinct from those which succeeded them. The difference is generally in the direction of greater primitiveness of structure in the older forms, Paleozoic types standing in somewhat the same relation to subsequent types as the embryo does to the adult.

"In the vast periods of time included in the Paleozoic era occurred some remarkable climatic vicissitudes. Times of widespread glaciation occurred in the Lower Cambrian of Norway and China, probably of Australia and perhaps also of South Africa, in the Devonian of South Africa and in the Permian of the latter region, India, Australia and South America, perhaps also in Europe and North America.

For most of the era, however, the climate appears to have been mild and equable on the whole, very much the same kinds of animals and plants occurring in high as in low latitudes. In short, we can detect no evidence of climatic zones as being distinctly marked in those periods."

So far as they are accessible to observation, the Cambrian rocks are chiefly such as are laid down in shallow water near shore, conglomerates, sandstones and shales, which are ripple-marked in a way that betrays their shoal-water origin. During Cambrian times the sea was slowly advancing over the land in North America, and the geography of the continent was very different at the close of the period from what it had been at the beginning. In the Lower Cambrian the land areas are inferred to have been somewhat as follows: First there was the great northern mass of crystalline Archæan and Algonkian rocks, but this was probably much more extensive than the present exposures of pre-Cambrian rocks would indicate. It probably covered the whole Mississippi valley down to 30° N. lat. and extended westward beyond the Rocky Mountains. Long, narrow strips of land, alternating with narrow sounds, occupied part of New England and the maritime provinces of Canada, while an Appalachian land, whose western line is marked by the present Blue Ridge, extended eastward an unknown distance into the Atlantic. On the western shore of the Appalachian land was a narrow arm of the sea, which opened south and nearly separated this land area from the great mass of the continent. The site of the Sierra Nevada was occupied by a long, narrow land, running from Puget Sound to Mexico, and another such area was found in eastern British Columbia. The Great Basin region was under water. Around these shores were laid down the coarser deposits of the Lower Cambrian, with great masses of shales and thick limestones in deeper water.

Much interest necessarily attaches to Cambrian fossils, for excepting the few and obscure organic remains obtained from pre-Cambrian strata, they are the oldest assemblage of organisms yet known. They form no doubt only a meager representation of the fauna of which they were once a living part. One of the first reflections which they suggest is that they present far too varied and highly organized a suite of organisms to allow us for a moment to suppose that they indicate the first fauna of our earth's surface. Unquestionably they must have had a long series of ancestors, tho of these earlier forms such slight traces have yet been recovered. Thus, at the very outset of his study of stratigraphical geology, the observer is confronted with a proof of the imperfection of the geological record. When he begins the examination of the Cambrian fauna, so far as it has been preserved, he at once encounters further evidence of imperfection. Whole tribes of animals, which almost certainly were represented in Cambrian seas, have entirely disappeared, while those of which remains have been preserved belong to different and widely separated divisions of invertebrate life.

Of the plants of the Cambrian strata nothing is surely known. Certain marks on the bedding-planes of strata have been regarded as seaweeds, but they are too obscure for determination and many are worm tracks.

The fauna is principally made up of Trilobites and Brachiopods, but many other types are represented also. Trilobites have a more or less distinctly three-lobed body, at one end of which is the head-shield, usually with a pair of fixed compound eyes; at the other end is the tail-shield, and between the two shields is a ringed or jointed body made up of a variable number of movable segments. The Trilobites display an extraordinary variety in form and size, in the proportions of the head and tail shields, in the number of free segments and in the development of spines. Brachiopods are among the most abundant of Cambrian fossils. Most of them belong to the lower order of the class, "Inarticulata," in which the shells are mostly horny and the two valves are not articulated together by a hinge. The horny-shelled types, "Linnarssonia," "Lingulepis" and "Lingulella," are of great interest, as they differ but little from certain brachiopods which still exist. The second order of Brachiopods, the "Articulata," which have calcareous shells connected by an elaborate hinge, were more common in the Upper Cambrian.

"Sir Roderick Murchison divided his great Silurian system primarily into two parts, Upper and Lower. This method of classification is generally followed even at the present day, altho it is widely recognized that the most decided break in the entire Paleozoic group is the one between these divisions. In 1879 Professor Lapworth proposed to give due emphasis to this distinction by erecting the Lower Silurian into a separate system, the "Ordovician." The name is taken from the "Ordovici," an ancient British tribe which dwelt in Wales during Roman times. Lapworth's example is now largely followed in England and the United States, but on the continent of Europe the name "Silurian" is still retained for both systems.

"The passage from Cambrian to Ordovician was gradual, without any marked physical break. Only where the Upper Cambrian is sandy, as in New York, is there a decided change in the character of sedimentation. In the latter part of the Cambrian a great inland sea had been established over what is now the Mississippi valley and, with frequent fluctuations in depth and modifications in form, it was to persist for long periods as one of the salient features of Paleozoic geography. This sea was separated from the Atlantic by the land mass called Appalachia, and on the western side it was demarcated from the Pacific by islands of undetermined size.

"At the end of the period came a time of widespread disturbance, upheaval and mountain-making, the traces of which are still plain in North America and Europe, especially along the Atlantic slope of each continent. The Interior Sea appears to have been entirely drained; at all events no deposits transitional to the Silurian are known from that region. In the West and Northwest large areas remained land for long periods, but the Interior Sea was soon reëstablished in the Mississippi valley. Some narrow strips of land were added to the margin of the Cambrian coasts, and on a line running through southern Ohio, Kentucky and Tennessee a low, broad arch, the formation of which appears to have begun early in the Ordovician, was forced up by lateral compression. This is called the "Cincinnati anticline or axis."

"Ordovician life displays a notable advance over that of the Cambrian, becoming not only very much more varied and luxuriant, but also of a distinctly higher grade. During the long ages of the period also very decided progress was made, and when the Ordovician came to its close all of the great types of marine invertebrates and most of their more important subdivisions had come into existence. In a general way the life of the Ordovician is an expansion of that of the Cambrian, tho but little direct connection between the two can yet be traced, and evidently there were great migrations of marine animals from some region which cannot yet be identified. Several groups of invertebrates attained their culmination and began to decline in the Ordovician, becoming much less important in subsequent periods. Thus the Graptolites, the Cystoidean order of Echinoderms, the straight-shelled Cephalopods (orthoceratites) among Mollusks, and the Trilobites were never so abundant and so varied as during this period.

"In America no plants above the grade of seaweeds and coralline Algæ have been discovered, but in Europe a few of the higher Cryptogams are doubtfully reported. The flora of the Devonian, however, renders it highly probable that land plants were already well advanced in the Ordovician, and their remains may be discovered at any time. This must remain a matter of accident, for the known Ordovician rocks are almost all marine, which is not a favorable circumstance for the preservation of land plants. Such discoveries have, indeed, already been reported, but the evidence for them is not satisfactory.

"The general disturbance which closed the Ordovician period appears to have greatly increased the extent of the continent. An important feature in the Silurian geography of eastern North America was the establishment of the "Cumberland Basin," or "Appalachian Mediterranean" as it has been called. This large sea lay to the eastward of the Interior Sea, from which it would seem to have been either completely separated or so nearly so that the species of marine animals inhabiting the two bodies of water were very different. The

Cumberland Basin was east of the Catskill-Helderberg line in New York and its western shore crossed New Jersey and curved westward beyond the center of Pennsylvania, whence it ran southwest more or less parallel with the Appalachian line, toward which it curved eastward in southern West Virginia. The Interior Sea underwent a succession of oscillations much like those which had affected it during the Ordovician; it was apparently closed at the south, but extended northwestward to the Arctic Sea, while its east-west diameter had been greatly reduced from that of the Ordovician.

Silurian life is the continuation and advance of the same organic system as flourished in the Ordovician, certain groups diminishing, others expanding; and some new groups now make their first appearance.

In parts of North America the Silurian passed so gradually and gently into the Devonian that it is difficult to draw the line between the two systems. Some disturbances, however, took place in Ireland, Wales and the north of England, for in these localities the Devonian lies unconformably upon the Silurian. In other parts of Europe the transition was gradual.

"Comparing the rocks of the Ordovician, Silurian and Devonian as these are developed in the Appalachian and adjoining regions, a certain rhythmic or periodic recurrence of events may be discovered among them. Each system is characterized by a great and very widespread limestone formation, and in each the limestone is succeeded by shales or other clastic rocks, due to an increase of terrigenous material, and each was closed by a more or less widespread emergence of the sea-bottom. Each began with a subsidence which gradually extended to a maximum at the time when the great limestone was formed. The parallelisms are not exact, but they are certainly suggestive.

"The European Devonian appears in three different facies; one of these is the 'Old Red Sandstone,' which is largely of continental origin and lies to the north. The second facies is of marine, shoal-water deposits and runs from Devonshire, through Belgium, the northern part of the lower Rhenish and the Hartz Mountains to Poland; and the third, extending from northwestern France, through Germany to Bohemia, was laid down in deeper water.

"The period began in Europe with an advance of the sea over the land in many places, reaching its maximum extension in the latter part of the period, but beginning to retire before the opening of the Carboniferous. This subsidence removed the barrier which in Ordovician and Silurian times had separated the northern and southern seas, but was accompanied by the formation of closed basins farther to the north. Europe then was largely an open sea with many islands, and where the waters were sufficiently clear and free from terrigenous sediment coral reefs were extensively formed.

"The 'Old Red Sandstone' is of particular interest, because owing to the peculiar circumstances of its formation it has preserved a record of Devonian land life, which, tho fragmentary, is far more complete than anything we possess from the more ancient periods. These strata were laid down in closed basins (sometimes, perhaps, in fresh-water lakes), which had only a restricted communication with the sea, and it may be that these accumulations were partly made by the wind, tho there is no gypsum or salt in the beds to indicate the prevalence of desert conditions.

"The life of the Devonian is, in its larger outlines, very like that of the Silurian, but with many significant differences, which are due, on the one hand, to the dying out of several of the older groups of animals, and on the other, to the great expansion of forms which in the Silurian had played but a subordinate rôle.

"The fossils show that in Devonian times the land was already clothed with a varied, rich and luxuriant vegetation of the same general type as that whose scanty traces are found in Silurian strata. All the higher Cryptogams are represented, and by large tree-like forms as well as by small herbaceous plants."

The Carboniferous system of rocks has received its name from the seams of coal which form one of its distinguishing characters in many parts of the world. Both in Europe and America it may be seen passing down conformably into the Devonian and Old Red Sandstone. So insensible indeed is the gradation in many consecutive sections where the two systems join each other that no sharp line can there be drawn between them. This stratigraphical passage is likewise frequently associated with a corresponding commingling of organic remains, either by the ascent of undoubted Devonian species into the lower parts of the Carboniferous series or by the appearance in the Upper Devonian beds of species which attained their maximum development in Carboniferous times. Hence there can be no doubt as to the true place of the Carboniferous system in the geological record.

In some places, however, the higher members of this system are found resting unconformably upon Devonian or older rocks, so that local disturbances of considerable magnitude occurred before or during the Carboniferous period. In Russia, and still more in China and western North America, Carboniferous rocks cover thousands of square miles in horizontal or only very gently undulating sheets.

The Carboniferous is divisible into two sharply marked portions, the Lower, or Mississippian, and Upper, or Pennsylvanian, a distinction which is applicable in all the continents in which the strata of this period have been carefully studied.

During this period the Interior Sea expanded widely, probably covering nearly the whole of the Great Plains, and most of the old land areas of the West and Southwest, which had persisted through more or less of the Silurian and Devonian, were extensively submerged, probably including all of Mexico and the northern part of Central America. West of the Rocky Mountains the Carboniferous is much the most widely extended of any of the Paleozoic systems, the sea reaching through British Columbia on both sides of the Gold Range into southeastern Alaska.

The remarkable profusion of the vegetation of the Carboniferous period, not only in the Old World but in the New, suggested the idea that the atmosphere was then much more charged with carbonic acid than it now is. Undoubtedly there has been a continual abstraction of this gas from the atmosphere ever since land-plants began to live on the earth's surface, and it is allowable to infer that the proportion of it in the air in Paleozoic time may have been somewhat greater than now. But the difference could hardly have been serious, otherwise it seems incredible that the numerous insects, labyrinthodonts and other air-breathers could have existed. Most probably the luxuriance of the flora is rather to be ascribed to the warm moist climate which in Carboniferous times appears to have been spread over the globe even into Arctic latitudes. On the other hand, evidence has been adduced to support the view that in spite of the genial temperature indicated by the vegetation there were glaciers even in tropical and subtropical regions.

The life of this period is thoroly Paleozoic and continues along the lines already marked out in the Devonian, but there are some notable changes and advances which look toward the Mesozoic order of things.

"The Carboniferous vegetation," Scott points out, "is of very much the same character as that of the Devonian, but owing to the peculiar physical geography of the times the plants were preserved as fossils in a much more complete state and in vastly larger numbers. The flora is composed entirely of the higher Cryptogams and the Gymnosperms, no plant with conspicuous flowers having come into existence, so far as we yet know. By far the most abundant of Carboniferous plants are the "Ferns," Filicales, which flourished in multitudes of species and individuals, both as tall trees and as lowly herbaceous plants. Many of these ferns cannot yet be compared with modern ones, because the organs necessary for trustworthy classification have not been recovered, and such are named in accordance with the venation of the leaves. In other cases the comparison with existing ferns may be definitely made, and these remains show that many of the modern families had representatives in the Carboniferous forests and swamps."

In North America the Permian followed upon the Carboniferous with hardly a break, so that the distinction between the two systems must be made entirely upon the fossils, which change very gradually, by drawing a somewhat arbitrary line of demarcation. In various countries there is no general agreement regarding the upper boundary of the Carboniferous. The Lower Permian of Europe is remarkable for the great masses of volcanic rocks, lava flows and tuffs which it contains and which occurs in Great Britain, France, Germany and the Alps. This is in strong contrast to the corresponding American series, which gives no evidence of vulcanism.

The animals and plants of the Permian are transitional between those of the Paleozoic and those of the Mesozoic eras. Here are found the last of many types which had persisted ever since Cambrian times, associated with forms which represent the incipient stages of characteristic Mesozoic types, together with others peculiar to the Permian. The flora of the Lower Permian is decidedly Paleozoic in character and that of the Upper Permian as decidedly Mesozoic, so that if the line dividing these two great eras were drawn in accordance with the vegetation, it would pass through the Permian. Even in the Lower Permian, however, the change from the Carboniferous flora is a marked one, a change which may be largely explained by the increasing aridity of the climate.

The Mesozoic formations have been grouped in three great divisions, which, tho first defined in Europe, are found to have their representative series of rocks and fossils all over the world. The oldest of these is the Trias or Triassic system, followed by the Jurassic and Cretaceous. "The life of the Mesozoic," Scott continues again, "constitutes a very distinctly marked assemblage of types, differing both from their predecessors of the Paleozoic and their successors of the Cenozoic. In the course of the era the Plants and marine Invertebrates attained substantially their modern condition, tho the Vertebrates remain throughout the era very different from later ones. Even in the Vertebrates, however, the beginnings of the newer order of things may be traced. In the earlier two periods, the Triassic and Jurassic, vegetation is almost confined to the groups of 'Ferns,' 'Cycads' and 'Conifers,' but with the Cretaceous come in the 'Angiosperms,' both 'Monocotyledons' and 'Dicotyledons,' and since then the changes have been merely in matters of detail.

"Among the 'Crustacea,' the 'Trilobites' and 'Eurypterids' went out, but all the modern groups were well represented, tho many of the Mesozoic genera are no longer to be found in the seas of to-day. Insects reached nearly their modern condition so far as the large groups are concerned, butterflies, bees, wasps, ants, flies, beetles, etc., being added to the older orthopters and neuropters.

"Fishes became modernized before the close of the era, the Bony Fishes having acquired their present predominance. The Amphibia took a subordinate place, and after flourishing for a time, the great Stegeocephalia died out, leaving only the pigmy salamanders and frogs of the present. Birds and Mammals made their first appearance, the former advancing rapidly to nearly their present grade of organization, tho not reaching their present diversity, while the mammals remained throughout the era very small, primitive and inconspicuous. The most significant and characteristic feature of Mesozoic life is the dominance of the Reptiles, which, in size, in numbers and in diversified adaption to various conditions of life, attained an extraordinary height of development. The Mesozoic is called the 'Era of Reptiles,' because these were the dominant forms of life. They filled all the rôles now taken by birds and mammals; they covered the land with gigantic herbivorous and carnivorous forms, they swarmed in the sea, and, as literal flying dragons, they dominated the air. At the present time there are only five orders of reptiles in existence, and of these only the crocodiles and a few snakes attain really large size. In the Mesozoic era no less than twenty-five reptilian orders flourished, and many of them had gigantic members. Some were the largest land animals that ever existed, and the sea dragons rivaled the whales in size. Nothing so clearly shows that the Mesozoic era is a great historical fact as the dominance of its reptiles.

"The Triassic Period is so named from the very conspicuous threefold subdivision of this system of strata in Germany, where its rocks were first studied in detail and where they occupy a greater area than in any other European country. The German Trias is, however, not the usual facies of the system, but a very peculiar one, and cannot be taken as the standard of comparison for most other countries. In the early part, at least, of the period both North and South America extended farther east than at present, and no marine Triassic rocks are known on the Atlantic slope of either continent, but they are extensively displayed on the Pacific side. The land barrier which during the Paleozoic era had bounded the Great Basin sea on the west was submerged and the Pacific extended over the site of the Sierras, covering western Nevada and sending a gulf into southeastern Idaho, and in British Columbia it transgressed eastward across the present mountains and it covered part of the coast of Alaska.

"On the Atlantic side of North America the course of events was entirely different. In the latter half of the period was formed a series of long, narrow troughs, running closely parallel to the trend of the Appalachian Mountains, but separated from them by the ridges of metamorphic and crystalline rocks which follow those mountains on the east, and which then probably had a considerable altitude, much greater than at present. In those troughs was laid down the enormous thickness of non-marine rocks which constitute the Newark series and are now found in several disconnected areas from Nova Scotia to North Carolina.

"Triassic life is entirely different from anything that had preceded it, tho the way for the change was already preparing in the Permian The Upper Permian, if classified by its plants alone, would be referred to the Mesozoic rather than to the Paleozoic; therefore it is not surprising that the Triassic flora is very similar to that of the Upper Permian, tho the Upper Trias marks a decided advance among the plants. Among the animals a considerable number of surviving Paleozoic types persist into the Trias which do not pass into the Jurassic."

William Smith, the father of Historical Geology, was the first to work out the divisions of the Jurassic, which he did early in the last century. Smith's name for the system, "Oölitic," has been abandoned in favor of the term Jurassic, which was first used by Brongniart and Humboldt. It was taken from the Jura Mountains of Switzerland, where the rocks of this system are admirably displayed. In Europe the Jurassic has long been a favorite subject of study, because of the marvelous wealth of beautifully preserved fossils which it contains. For this reason the Jurassic is known with a fullness of detail such as has been acquired regarding very few of the other systems; and no less than thirty well-defined subdivisions have been traced through many countries of the Old World. In this country the Jurassic is ill represented and its divisions are not clear.

"The life of the Jurassic has been preserved in wonderful fulness and variety; but with comparatively few exceptions our knowledge of it has been principally derived from Europe, where a host of eminent geologists have long studied the great wealth of material. The contrast between North America and Europe in regard to the relative abundance of Jurassic marine fossils is seen from the fact that while in Great Britain alone more than 4,000 species have been described, in America hardly one-tenth of that number has so far been found. The flora of the Jurassic differs little, on the whole, from that of the Trias, and is made up of Ferns, Horsetails, Cycads, Conifers and Gingkos.

"The name 'Cretaceous' is derived from the Latin word for chalk, 'Creta,' because in England, where the name was early used, the thick masses of chalk are the most conspicuous members of the system. Tho first made known in England, the main subdivisions of the Cretaceous, as employed in geological literature, bear French names, which have proved themselves better adapted to general use.

"In very marked contrast to the scanty development of the Jura, the Cretaceous strata of North America are displayed on a vast scale and cover enormous areas of the continent, eloquent witnesses of the great geographical changes in that long period. Continental, estuarine and marine rocks are all well represented, and, in consequence, our information regarding the life of North America and its seas during

Cretaceous times is incomparably more complete than it is for the Triassic and Jurassic.

"It was during the Upper Cretaceous that the great subsidence took place which affected nearly all parts of the continent and brought the sea in over vast areas where for ages had been dry land. South of New England the Atlantic coastal plain was submerged, and in New Jersey, at least, the waters covered even the nearly base-leveled Triassic belt, bringing the sea up to the foot of the crystalline highlands. The lowlands of Maryland, Virginia and the Carolinas and all of Florida were under the ocean, and the Gulf of Mexico was extended northward in a great bay (the Mississippi embayment), covering western Tennessee and Kentucky and extending into southern Illinois.

"In the southern region the Lower Cretaceous was terminated by an upheaval, which caused the Comanchean Sea to withdraw from Texas and the area to the west and north of it. This mid-Cretaceous land epoch must have continued for a considerable time, permitting extensive denudation and a complete change in the fauna. Wherever the marine Upper Cretaceous is in contact with the Comanche limestones north of Mexico the two are uncomformable, and no species of animal is known to pass from one to the other. In Mexico the Lower Cretaceous passes into the Upper without a break, the disturbances there taking place at a later date.

"The Mesozoic era was closed in the West, as the Paleozoic had been in the East, by a time of great mountain making, and to this movement is attributed the formation of most of the great Western mountain chains. From the Arctic Ocean to Mexico the effects of the disturbance were apparent. The Rocky Mountains, the Wasatch and Uinta ranges, the high plateaus of Utah and Arizona and the mountains of western Texas date from this time, tho subsequent movements have greatly modified them. Vast volcanic outbreaks accompanied the upheaval, which was on a far grander scale than the Appalachian revolution had been.

"The life of the Cretaceous displays so great an advance over that of the Jurassic that the change may fairly be called a revolution. In the latter part of the Lower and in all the Upper Cretaceous of North America the flora assumes an almost completely modern character, and nearly all of our common kinds of forest trees are represented: Sassafras, Poplars, Willows, Oaks, Maples, Elms, Beeches, Chestnuts and very many others. A new element is the Monocotyledonous group of Palms, which speedily assumes great importance. Cretaceous animals are sufficiently different from those of the Jurassic, but the change is not so revolutionary as has been found among the plants.

"The life of the Cenozoic era is very clearly demarcated from that of the Mesozoic, tho many modern characteristics began in the Cretaceous or even earlier. The plants and invertebrate animals nearly all belong to genera which are still living, and the proportion of modern species steadily increases as we approximate the present time. The Fishes, Amphibia and Reptiles differ but little from those of modern times, and the Birds take on the diversity and relative importance which characterize them now. Above all, the Mammals undergo a wonderful expansion and take the place of the vanished reptiles, giving to Cenozoic time an altogether different character from all that went before it. The great geographical and climatic changes produced migrations of land animals and plants upon a grand scale, from continent to continent and from zone to zone, the result of which is the distribution of living beings over the earth's surface as we find it today."

The Tertiary Period witnessed the development of the present distribution of land and sea and the final upheaval of most of the great mountain-chains of the globe. Some of the most colossal disturbances of the terrestrial crust of which any record remains took place during these periods. Not only was the floor of the Cretaceous sea upraised into low lands, with lagoons, estuaries and lakes, but afterward, throughout the heart of the Old World, from the Pyrenees to Japan, the bed of the early Tertiary or nummulitic sea was upheaved into a succession of giant mountains, some portions of that sea-floor now standing at a height of at least 16,500 feet above the sea.

During Tertiary time there was an abundant manifestation of volcanic activity. After a long quiescence during the succession of Mesozoic periods volcanoes broke forth with great vigor both in the Old and the New World. Vast floods of lava were poured out and a copious variety of rocks was produced, ranging from highly basic basalts, limburgites and peridotites to rhyolites, quartz-felsites and granites.

The name Tertiary was given by Cuvier and Brongniart early in the last century to the succession of marine, brackish-water and fresh-water beds in the Paris basin. Sir Charles Lyell many years later proposed the division of the Tertiary into three parts, Eocene (from the Greek eos, the dawn, and kainos, recent), Miocene (meion, less, and kainos) and Pliocene (pleion, more, and kainos), a scheme which is still used, modified by Beyrich through the insertion of a fourth epoch, the Oligocene (oligos, little or in small degree, and kainos). Last of all, the Lower Eocene has been separated under the name Paleocene (palaios, ancient, as in Paleozoic), a change proposed thirty years ago by the botanist Schimper, but only lately coming into wider favor. It has become customary to distinguish between the older and newer parts of the Tertiary by grouping together the

Eocene and Oligocene into the Paleogene and the Miocene and Pliocene into the Neogene.

The Post-Tertiary or Quaternary portion of the Geological Record includes the various superficial deposits in which nearly all the mollusca are of still living species. It is usually subdivided into two series: (1) An older group of deposits in which many of the mammals are of extinct species (to this group the names Pleistocene, Post-Pliocene and Diluvial have been given) and (2) a later series, wherein the mammals are all, or nearly all, of still living species, to which the names Recent, Alluvial and Human have been assigned. These subdivisions, however, are confessedly very artificial, and it is often exceedingly difficult to draw any line between them. The gradual refrigeration of climate at the close of the Tertiary ages affected the higher latitudes alike of the Old and the New World.

"As the cold increased," says Geikie, "the whole of the north of Europe came eventually to be buried under ice, which, filling up the basins of the Baltic and North Sea, spread over the plains even as far south as close to the site of London and in Silesia and Galicia to the 50th parallel of latitude. Beyond the limits reached by the northern ice-sheet the climate was so arctic that snow-fields and glaciers stretched even over the comparatively low hills of the Lyonnais and Beaujolais in the heart of France. The Alps were loaded with vast snow-fields, from which enormous glaciers descended into the plains on either side, overriding ranges of minor hills on their way. The Pyrenees were in like manner covered, while snow-fields and glaciers extended southward for some distance over the Iberian peninsula. In North America also, Canada and the Eastern States of the American Union, down to about the 40th parallel of north latitude, lay under the northern ice-sheet.

"Owing mainly to the direction of the prevalent moisture-bearing winds, the snowfall was greatest toward the west and northwest, and in the direction of Scandinavia the ice-sheets attained their greatest thickness. The Scandinavian ice joined that which spread over Britain, where the dimensions of the sheet were likewise great. Many mountains in the Scottish Highlands show marks of the ice-sheets at heights of 3,000 feet and more. If to this depth be added that of the deep lakes and fjords which were filled with ice, it is evident that the sheet may have been as much as 4,000 or 5,000 feet thick in the northern parts of Britain.

"This vast icy covering, like the Arctic and Antarctic ice-sheets of the present day, was in continual motion, slowly draining downward to lower levels. Toward the west its edge reached the sea, as in Greenland now, and must have advanced some distance along the sea-floor until it broke off into bergs that floated away northward. Toward the south and east it ended off upon land and no doubt discharged copious streams of glacier-water over the ground in its front. In northern Germany, Denmark, Finland and Scandinavia, the southern limits at which the ice rested a long while before retiring are indicated by long winding ramparts of detritus (Endmoräne). In North America also the southern edge of the ice-sheet is marked by similar 'terminal moraines,' which are well displayed from Pennsylvania to Dakota.

"When this glaciation took place the terrestrial surface of the northern hemisphere had acquired the main configuration which it presents to-day. The same ranges of hills and lines of valley which now serve to carry off the rainfall served then to direct the results of the snowfall seaward. The snow-sheds of the Ice Age probably corresponded essentially with the water-sheds of the present day. Yet there is evidence that the coincidence between them was not always exact. In some cases the snow and ice accumulated to so much greater a depth on one side of a ridge than on the other that the flow actually passed across the ridge, and detritus was carried out of one basin into another. A remarkable instance of this kind has been observed in the north of Scotland, where so thick was the ice-sheet that fragments of rock from the center of Sutherland have been carried up westward across the main water-parting of the country and have been dropped on the western side.

"In North America also abundant evidence is afforded of a northern ice-sheet which overrode Canada and the Eastern States, southward to about the 40th parallel of latitude in the valley of the Missouri. Several centers of dispersion have been noted from which this ice moved outward, chiefly in a general southerly direction, but in the middle part the ice streamed northward into the Arctic Ocean. The great mountain ranges farther south likewise nourished numerous glaciers, which radiated outward from the high ground.

"As great oscillations of climate took place during the Ice Age and in some cases probably lasted for a long time, the plants and animals both of land and sea could hardly fail to be seriously affected. During the cold intervals northern forms would probably migrate southward and in the warmer episodes southern forms would push their way northward. The Arctic terrestrial animals include the mammoth wooly rhinoceros, musk-sheep, reindeer, Arctic fox and lemming. The marine invertebrate fauna shared, tho in a less degree, in the effects of the meteorological and geographical changes. During the times of great cold northern species found their way southward, some of them even as far as the basin of the Mediterranean."

The cause of the remarkable change of climate during late Tertiary and post-Tertiary time has given rise to much discussion, but is still without a completely satisfactory explanation. Some writers have favored the view that there has been a change in the position of the earth's axis or of its center of gravity. Others have suggested that the earth may have passed through hot and cold regions of space. Others, again, and notably Lyell, have called in the effects of stupendous terrestrial changes in the distribution of land and sea, on the assumption that elevation of land about the poles must cool the temperature of the globe, while elevation round the equator would raise it. But the amount of geographical transformation thus involved was so great and the evidence for it appeared to be so slender that geologists generally have been reluctant to accept this explanation. In the difficulty of accounting for the phenomena by any feasible operation on the earth itself, they by degrees accustomed themselves to the belief that the cold of the Glacial Period was not due to mere terrestrial changes, but was to be explained somehow as the result of cosmical causes.

Among the recent attempts to deal with the problem of the Ice Age is the hypothesis proposed by Professor Chamberlain on the basis of variations in the amount of carbon dioxide in the air. It is founded on the capacity of that gas for absorbing heat and to the effect that might be produced on the temperature of the air by even a comparatively small increase of diminution in the proportion of the gas. The suggestion is that while there is a general tendency to the diminution of that proportion there arise from time to time conditions, such as great volcanic discharges, whereby much carbonic dioxide is supplied to the atmosphere. On this view the Glacial Period would mark a time of great depletion of the gas, while the Arctic Miocene flora would indicate a time of comparative enrichment. Other geologists have turned back to the idea of geographical changes. That considerable oscillations of the relative levels of land and sea took place during the Ice Age has been clearly determined. The general result of investigation favors the opinion that the land in the early part of that period stood much higher than now over the northern regions of Europe and North America. If one accepts the conclusions drawn from the prolongation of land-valleys upon the sea-floor to a depth of many hundred feet and from the distribution of dead littoral and shallow-water shells down to depths of 6,000 or 8,000 feet in the North Atlantic, it can be seen that a vast area of high land would, under these conditions, have existed. This higher elevation would undoubtedly tend to lower the temperature. Some of the upraised parts of the sea-floor might deflect warm ocean currents and thus still further increase the cold in the higher latitudes. But no satisfactory attempt has yet been made to trace out these changes geographically on actual evidence of their having occurred and to connect them with the phenomena of the Pleistocene Period.

The long succession of Pleistocene ages shaded without abrupt change of any kind into what is termed the Human or Recent Period. The Ice Age, or Glacial Period, may indeed be said still to exist in Europe. The snow-fields and glaciers have disappeared from Britain, France, the Vosges and the Harz, but they still linger among the Pyrenees, remain in larger mass among the Alps and spread over wide areas of northern Scandinavia. This dovetailing or overlapping of geological periods has been the rule from the beginning of time, the apparently abrupt transitions in the geological record being due to imperfections in the chronicle.

"The Human Period," resumes Geikie, "is above all distinguished by the presence and influence of man. It is difficult to determine how far back the limit of the period should be placed. The question has often been asked whether man was coeval with the Ice Age. To give an answer, we must know within what limits the term Ice Age is used and to what particular country or district the question refers. For it is evident that even to-day man is contemporary with the Ice Age in the Alpine valleys and in Finland. There can be no doubt that he inhabited Europe after the greatest extension of the ice. He not improbably migrated with the animals that came from warmer climates into this continent during interglacial conditions. But that he remained when the climate again became cold enough to freeze the rivers and permit an Arctic fauna to roam far south into Europe is proved by the abundance of his flint implements in the thick river-gravels, into which they no doubt often fell through holes in the ice as he was fishing.

"The proofs of the existence of man in former geological periods are not to be expected solely or mainly in the occurrence of his own bodily remains as in the case of other animals. His bones are indeed now and then to be found, but in the vast majority of cases his former presence is revealed by the implements he has left behind him, formed of stone, metal or bone. The history of the Bronze and Iron Ages in Europe is told in great fulness, but belongs more fittingly to the domain of the archeologist, who claims as his proper field of research the history of man upon the globe. The remains from which the record of these ages is compiled are objects of human manufacture, graves, cairns, sculptured stones, etc., and their relative dates have in most cases to be decided, not upon geological but upon archeological grounds. When, however, the sequence of human relics can be shown by the order in which they have been successively entombed, the inquiry is strictly geological and the reasoning is as logical and trustworthy as in the case of any other kind of fossils."

The Age of the Earth is another matter which geologists must needs speak of in terms of extreme guardedness. Reasoning by analogy, it is true, there is a certain standard to be secured. Thus, for example, when it is discovered that water flowing at a certain speed cuts away the particles of a certain rock so many fractions of an inch in a decade, it is assumed that where so many feet have been cut away from a certain rock by the influence of water, the proportion so cut away must represent so many multiples of the fraction of an inch cut away in a decade, and therefore the time that has been since the beginning of the cutting away of that gorge (such as Niagara) is an equivalent number of multiples of the decade of years.

But while this affords an excellent basis for rough estimation, it is not to be forgotten that it acts entirely on the assumption that matter was in those early days as it is now and that the forces are unchanged. This assumption, however useful, cannot be termed strictly scientific, for there is no means of determining whether the original groove, for example, may not have been made in the time when the rock was in a viscous state or even so superheated that water would cause violent fractures, since worn smooth.

The same holds true with sedimentation. A certain land is regarded as being so many thousands or million of years in age because of the rate at which it has been laid down in sediment. But geologists are becoming even more wary of this, especially since the discovery of some coins in a bog in Germany, which, according to the estimates of the laying down of peat, must have been 18,000 years old, and yet which were found to have the stamp of Claudius Cæsar.

The physical argument, moreover, that changes in plants and animals have taken a long while to produce is purely dependent upon a certain theory of variation in biology, a theory by no means certain or approved. Thus, to give the best-known modern instance, in the space of ten years Hugo de Vries, the great Amsterdam botanist, has observed a variation in the Evening Primrose, which is permanent and reproductive, yet which according to the older ideas of infinitely slow variation would have been presumed to have taken hundreds, if not thousands, of years. More, if the forces of life were stronger in their youth (as is not an impossible assumption) changes could and probably would occur with greater variety and at higher speeds than at the present time, when the force has been worked over and over for myriad centuries.

An ingenious geological argument has been based by Prof. J. Joly, of Trinity College, Dublin, on the quantity of sodium present in the water of the ocean as a measure of the age of the earth. He assumes that the sodium contained in that water was not derived from the primeval atmosphere or the original constitution of the ocean, but has been supplied in the long course of geological time by the denudation of the land and the consequent removal of the material in solution from the terrestrial rocks. He arrives at the conclusion that if the present annual supply be taken as a measure of what has been the rate in past time, a period of between 90 and 100 millions of years has elapsed since the ocean began to receive its tribute of chemical solution from the land.

The geological argument for the age of the earth may be summed up thus: The geological evidence indicates an interval of probably not much less than 100 million years since the earliest forms of life appeared upon the earth and the oldest stratified rocks began to be laid down.

The physical argument as to the age of this planet is based upon three kinds of evidence: (1) The internal heat and rate of cooling of the earth; (2) the tidal retardation of the earth's rotation; and (3) the origin and age of the sun's heat. (1) Applying Fourier's theory of thermal conductivity, Lord Kelvin pointed out as far back as the year 1862 that the superficial consolidation of the globe could not have ocurred less than 20 million years ago, or the underground heat would have been greater than it is; nor more than 400 million years ago, otherwise the underground temperature would have shown no sensible increase downward. He would now restrict the time to between 20 and 40 millions. (2) The reasoning from tidal retardation proceeds on the admitted fact that, owing to the friction of the tidal-wave, the rotation of the earth is retarded, and is therefore slower now than it must have been at one time. Lord Kelvin contends that had the globe become solid some 10,000 million years ago, or indeed any high antiquity beyond 100 million years, the centrifugal force due to the more rapid rotation must have given the planet a very much greater polar flattening than it actually possesses. (3) The third kind of evidence leads to results similar to those derived from the two previous lines of reasoning. It is based upon calculations as to the amount of heat that would be available by the falling together of masses from space, which by their impact gave rise to our sun, and the rate at which this heat has been radiated. Assuming that the sun has been cooling at a uniform rate, Professor Tait concluded that it cannot have supplied the earth, even at the present rate, for more than about 15 or 20 million years. Lord Kelvin also believes that the sun's light will not last more than 5 or 6 millions of years longer.

Believing that "almost anything is possible as to the present internal state of the earth," Professor Perry concluded an article in "Nature" in these words: "To sum up, we can find no published record of any lower maximum age of life on the earth, as calculated by physicists, than 400 millions of years. From the three physical arguments, Lord Kelvin's higher limits are 1,000, 400 and 500 million years. I have shown that we have reasons for believing that the age, from all these, may be very considerably underestimated. It is to be observed that if we exclude everything but the arguments from mere physics, the probable age of life on the earth is much less than any of the above estimates; but if the paleontologists have good reasons for demanding much greater time, I see nothing from the physicist's point of view which denies them four times the greatest of these estimates."

CHAPTER XIV

THE STORY OF CRYSTALS

The physicist, as a result of his studies into the structure of different kinds of matter, has concluded that every body is built up of minute particles called molecules, which are much too small to be perceived even by the strongest microscope. When a liquid turns into a solid because the temperature falls, as when water freezes or liquid sulphur or molten iron hardens when cooling, the force of cohesion comes into play to bind these molecules together into a rigid mass. So also, when by slow evaporation from solution, as of salt or alum in water, the dissolving liquid is removed, the substance in solution also passes back into the solid form under the action of this same force of cohesion. Thus the solid is formed from the liquid by the action of the forces acting between these little particles.

Further, if the molecules are all of one kind, as in a given chemical substance, and if there are no hindering causes, these molecules will build themselves up after some regular pattern and the external result is the geometrical form which is called a crystal. This regular building of the molecules, which may take place from a liquid, happens also, even more perfectly, when a solid is formed direct from a gas. Water vapor in the air, if cooled down sufficiently, is formed into the solid snow, and the little snow-crystals that fall silently through the atmosphere are often of wonderful regularity and beauty of form.

In nature it often happens that the building process cannot go on freely, and imperfect crystals, or perhaps a mass with only a confused crystalline structure, and with only distinct external form, is all that is produced. The quartz, feldspar and mica in the rock called granite usually have formed together in such a way that neither one has had an opportunity to build itself up into perfect crystals, and yet the scientist who understands the optical study of thin sections of a rock in polarized light can prove that each grain, formless tho it may be externally, has all the internal molecular structure of the crystal. In the event of a cavity in the granite will be found crystals of quartz and feldspar, perhaps also of mica, as the cavity here means that each has had an opportunity to exercise its tendency to build itself regularly with something of the freedom which a perfect crystal requires.

Another familiar example of crystallization is given by the ice covering a pond, which is as truly crystalline in structure as the perfect snow-crystal; but here there are no crystals, and it is easy to understand why. The slow dissection of the mass, however, under the melting action of the sun reveals something of the regularity in the molecular building, and the same thing is proved by an examination in polarized light. Sometimes in the freezing of a little pool of water the formation of the slender crystalline ribs of ice may be watched as they shoot out, forming a framework which may soon lose its distinctness as the entire surface is frozen over.

Edward S. Dana, in his "Minerals and How to Study Them," defines a crystal as "The regular solid form which a chemical substance takes when it passes into the solid state from that of either a liquid or a gas, if under such conditions that the molecules are quite free to arrange themselves according to the direction of the attractive forces acting between them."

The crystal is, therefore, the outward expression of the structure in the arrangement of these molecules, and its form is for this reason the most important of all the physical character of a given species and the one which in general most definitely distinguishes it from others. "Crystals are therefore," says Professor Dana, "the perfect individuals of the mineral kingdom. The mineral quartz has a specific form and structure, as much as a dog or an elm, and is as distinct and unvarying as regards those characters, altho owing to controlling causes during formation these forms are not always assumed. In whatever part of the world crystals of quartz may be obtained, they are fundamentally identical."

It is interesting to note that a small crystal is just as perfect and complete an individual as a similar one of great size; there is among the crystals of a given species no such connection between size, on the one hand, and age and maturity, on the other, that belongs to the individuals of a species in the animal and vegetable kingdoms. Some crystals are so minute as to be almost microscopic; others may be of enormous size, as the gigantic quartz crystals occasionally found in the Alps, or the equally large beryl crystals from New Hampshire. A cave opened a few years ago at Macomb, New York, contained fifteen tons of great cubic crystals of fluorite; another cave in Wayne County, Utah, contained a great number of enormous crystals of gypsum, some of them three feet or more in length. But the very small crystals and the like ones of enormous size are not essentially different except in this comparatively unimportant respect of magnitude.

It is seldom that any mineral crystallizes alone. Usually two or three, under quite different crystalline laws, form together. "They do this," comments Ruskin, "absolutely without flaw or fault, when they are in fine temper; and observe what this signifies. It signifies that the two, or more, minerals of different natures agree, somehow, between themselves, how much space each will want; agree which of them shall give way to the other at their junction, or in what measure each will accommodate itself to the other's shape. And then each takes its permitted shape and allotted share of space, yielding, or being yielded to, as it builds till each crystal has fitted itself perfectly and gracefully to its differently natured neighbor.

"This seems to imply both concurrence and compromise, regulating all wilfulness of design; and, more curious still, the crystals do not always give way to each other. They show exactly the same varieties of temper that human creatures might. Sometimes they yield the required place with perfect grace and courtesy, forming fantastic but exquisitely finished groups, and sometimes they will not yield at all, but fight furiously for their places, losing all shape and honor, and even their own likeness in the contest."

It is an experiment of much ease and great delight to cause the growth of crystals. This may be done by dissolving certain compounds and allowing the solution to evaporate. Let three common substances, which can be found in every home, be used for the experiments—salt, alum and sugar.

First boil some water and add to the boiling water as much of the salt or the alum or the sugar as will dissolve. Pour part of this saturated solution into a saucer, and as the liquid cools and evaporates, some of the material held in solution will separate out in the form of bright, sparkling crystals on the bottom of the saucer. Meantime keep the rest of the solution hot. Pour this into a glass, and suspend one of the crystals formed in the saucer by a thread in the solution that has been poured into the glass. As this evaporates larger and better shaped crystals will be obtained. The reason for the second group of crystals being in more regular shape is that, in the saucer, in the course of growth, the crystals were flattened by not being able to "grow" equally in all directions. At the same time, the crystals in the glass grow more slowly, and slow growth is conducive to size.

When crystals of salt, of alum and of sugar have thus been secured, a fact of great interest and importance will be made clear. It will be seen that the salt has crystallized in the form of a cube, with six sides; the alum in the form of an octahedron, with eight sides; and the sugar into a tabular crystal, with rectangular outline. You can do what you please with that salt and that alum, but one will remain a cube, the other an octahedron to the end of time.

The next point to keep clearly in mind is that every substance in the world crystallizes in its own way, just as do the salt and the alum. As there is an endless number of minerals and their compounds, there must also be an endless variety of crystals. On the other hand, as crystals follow very definite geometrical laws, there can only be a certain definite number of types or classes. It has been found that there are thirty-two of these, divided into several systems.

With the best intentions in the world, there are certain subjects which cannot be discussed or explained without the use of some scientific and technical terms. The science of crystals is one of these subjects. A cube, for example, is a technical term. It is so familiar, however, in its shape of a perfect square, like a child's play block, that one is apt to forget its technical character. In crystallography, it is necessary to keep the shape of the cube well in mind.

Not quite as familiar as the cube, but still fairly easy to understand, is the octahedron. This is a solid, bounded by eight equal-sided or equilateral triangles. It can be easily made thus: Take an apple (as nearly round as possible) and three knitting needles. Thrust one needle through the core from the point of the apple stalk. Stick a second needle through the core from one side to the other. At the point of the circumference of the apple midway between the place where the ends of the last needle protrude, thrust a third needle. Then take a knife and, from the top of the apple, cut off four slices, beginning at the point where the first needle entered at the top, to the points on the surface where each of the other two needles entered the apple. This gives a pyramid effect to the upper half of the apple. Turn the fruit over, and do the same thing from the bottom. The apple will then look like two four-sided pyramids placed base to base. This is an octahedron.

Now, that apple can be divided exactly in half in three ways. It can be sliced in half through the core, beginning from the top, so that the knife will pass through the corners which represent the points where the second needle was inserted. Again, it may be sliced in half by passing the knife from the top through the points which represent where the third needle was inserted. Again, it may be sliced in half through the points where the second and third needles were inserted, not affecting the angles of the first needle at all. Each of these three ways of slicing will leave a four-sided pyramid. In technical terms, then, an octahedron has three planes of symmetry. It is easy to see that a cube can be sliced in half in three different ways, each slice shearing through two of its six facets. There are six other minor planes of symmetry, but, for the sake of simplicity, one may pass on.

If either the octahedron or the cube can be rotated on one of its points, it will be seen that four times in the revolution the cube and the octahedron will present the same appearance. This axis is known therefore, as a tetrad (four-times) axis. It can also be seen that there are three such axes in both the octahedron and the cube. These are the principal axes of symmetry. There are also six more axes of symmetry—four triad (three-times), and two dyad (twice appearing the same).

Just as an example, let us go one step further. Each face of the octahedron intersects all the three axes at equal distances from the center. Now, if a face that intersects two axes at equal lengths, and is parallel to the third, be used, twelve faces can be built up around the cubic axes, and a figure is made with twelve sides, each of the sides being the shape of a rhomb, or lopsided square. This is called a rhombic dodecahedron.

By truncating or cutting off the corners of the cube, an octahedral effect is given. Indeed, to the cube has been added the octahedron, and the figure is now fourteen-sided, and is known as a cubo-octahedron. Its planes and axes of symmetry, then, are similar to the cube and it belongs to the cubic system.

Thus, salt, native copper, iron pyrites, fluor-spar, etc., crystallize in cubes; the octahedron is represented by magnetite and the diamond; and the cubo-octahedron by galena (lead) and smaltite. The garnet crystallizes as a rhombic dodecahedron.

Corresponding to the octahedron, in a second system may be found a solid bounded by eight equal triangles. This is the primary form of a system known as the Tetragonal. In the next system is a solid bounded by eight equal triangles, but in this system (the Orthorhombic) the edges of the triangles are all unequal. In the Monoclinic or oblique system, the crystals possess only one plane of symmetry. In the Anorthic system, all the axes are of unequal lengths and they are all inclined at oblique angles; there is therefore neither plane nor axis of symmetry, but only a centre of symmetry. In the Rhombohedral system, the primary form is a solid bounded by six equal rhomb-shaped faces. The Hexagonal system resembles the Rhombohedral, but, instead of showing a threefold arrangement of faces about a vertical axis, there is a sixfold arrangement.

The growth of crystals is highly irregular so far as outward form is concerned, though the geometrical proportions remain true. Thus some minerals, such as barytes, form table-like crystals; others, like beryl, form columns; and others, again, like sulphide of nickel, form prisms so long and slender that the habit may be called hair-like. Since it is rare that crystals form without interference, nearly all natural crystals are found in confusion, the one forcing the other out of its proper shape. Occasionally two crystals are found together, twinned.

Many minerals, instead of growing as single and distinctly developed crystals, give rise to various kinds of structure or texture, due to the crowding together of a large number of crystal individuals. Loaf sugar to a great degree, and statuary marble to a lesser, show granular crystalline structure, as can be easily seen through a magnifying glass. If the crystalline grains are so small that they cannot be distinguished except under a microscope, then the structure is described as compact and the mineral is said to be massive. A broken surface of this character, except under the microscope, will not show crystalline.

Most of the crystals of minerals would give a very poor impression of nature's workmanship to one who expected always to see them exactly like carefully made models, or like the regular geometrical figures drawn of them. The cubes of galena are often flattened or drawn out. But it is not really to be supposed that the forms are badly made, like a bad model; on the contrary, the size of the like faces on a crystal may vary, and so the shape of the solid as a whole, but the angles between them remain the same. Moreover, what is really essential is not the size or shape of each face, but the way in which the little molecules of which the whole is built up are arranged. For example, in a cube the essential point is the fact that the structure is the same in the direction of the three cubic faces. It follows from this that in the cube not only are the angles between two adjacent faces always 90°, but the six cubic faces are all similar; and therefore if there is the easy fracture, called cleavage, parallel to one cubic face, there will be also the same cleavage parallel to the others. But the actual size of the faces is a matter of no importance. In fact, in one species the cubes are sometimes lengthened so as to be like fine hairs.

Similar remarks can be made in regard to any distorted form. The symmetry in the molecular structure, and hence the angles between the faces, remain unchanged, altho the symmetry of the external geometrical form is not that of the ideal crystal. A cube may in nature look like a square prism, for the angles between the faces are all right angles in both cases; but the molecular structure of the two is not to be confounded. In the square prism there is the same arrangement in the transverse directions, but a different one up and down; hence the square top of the crystal is not like the four similar oblong vertical faces, and there is cleavage parallel to one set and not to the other.

From this variation it is evident that the practical study of natural crystals is much more difficult than the study of the models which gave the ideal forms. This is especially true because most crystals are so implanted on the rock, or embedded in it, that only part of the form has been developed. Thus quartz crystals are often attached at one extremity, while only the other end has had a chance to grow freely. Or the crystals may be implanted upon a surface of rock so that only a series of minute faces and angles are visible. In such cases the study of the form is really a difficult matter requiring much skill and experience.

Besides the crystals that have been just spoken of, which, while they look at first irregular, are really perfect in the matter of the position of the faces and of the angles between them, there are others which are really deformed.

Some peculiar condition attending the growth of the crystal, or perhaps some force which has acted upon it since it was formed, has resulted in bending or twisting it out of its normal shape, so that it may differ widely in angle from the regular form. Thus the faces may be curved, as with the barrel-shaped crystals of pyromorphite, or like the peculiar convex faces common on crystals of the diamond; or the whole crystal may be bent, as is seen sometimes in crystals of quartz, stibnite, or of some kinds of chlorite.

Aside from this curving and twisting, a crystal may have had its shape more or less changed by some force exerted in the rock since it was made; it may even have been broken and again cemented together, so that many irregularities may result.

The salt-crystals sometimes show distinctly one face only with the depression in the center, so that they are called hopper-shaped crystals. The cavernous crystals of pyromorphite and vanadinite give other examples. Crystals, often for the same reason, enclose foreign substances, sometimes in the form of liquids, as the quartz crystals that contain water, occasionally with a movable bubble of air. Or the liquid may be carbon dioxide, then often with a bubble of the same substance in the form of gas. In such cases the crystal must have been formed under great pressure, sufficient to keep the gas in the liquid form. Fragments of such crystals heated in the gas-flame fly to pieces with great violence, because of the expansion of the gas formed from the liquid by heat.

A peculiar class of false forms, in which the crystalline shape does not belong to the chemical substance, must be briefly described here. These are called "pseudomorphs."

Pseudomorph means false form, and the name is applied to a specimen having the form characteristic of one species and the chemical composition of another. This seemingly difficult contradiction is easily explained. Most chemical compounds are liable to undergo a change or alteration when subjected to certain conditions, as moisture, the action of alkaline waters or acid vapors. Now, in these cases, if the original mineral was in crystals, the external form is usually preserved, often perfectly, while the chemical nature and the molecular structure have changed.

The cases where the original substance has entirely disappeared and some other has come in to take its place are also called pseudomorphs. Thus occasionally quartz is found in the form of calcite, or of fluorite, or of barite; that is, pseudomorph after one of these; also tin-stone in the form of orthoclase feldspar; native copper in the form of aragonite. Even fossil wood may be said to be a pseudomorph of quartz or opal after the original wood, the structure of which it sometimes preserves with wonderful perfection.

Some crystals occur isolated and alone, and then the form is usually developed on all sides, and with something of the regularity which the ideal model shows. Thus are found perfect garnets in mica schist or granite, and gypsum crystals in clay. But it is still more common to find crystals grouped together either irregularly, as in the majority of cases, or perhaps in parallel position, or again in the peculiar way called twinning.

It is evident that, since the crystals on a single specimen of a species may be grouped in a great variety of ways, it is not always easy to decide whether a given case is a twin or not; this often becomes a matter requiring careful study, exact measurement of angles, and calculation, perhaps also of optical study. For example, it is common to find quartz crystals crossing each other at a great variety of angles, but true quartz twins are rare. The two parts of a true twin are usually symmetrical with reference to the twinning plane, and there is always the reversal of one half.

One very common case of the grouping of crystals, which is apt to to confounded with twinning, is where the crystals or parts of crystals are parallel to each other, so that the axes of all have the same directions, and are not inclined as in most twins. This is illustrated by a pile of cubes with faces parallel and having reëntrant angles between them. The crystals of many species are at times arranged in this way, but in every case it will be found that if the complex group is held so as to reflect the light from a window, the faces in adjoining crystals which reflect at the same time always similar faces. An octahedron of fluorite, built up of a multitude of little cubes in parallel position, is a not very rare example of this.

Parallel grouping is most interesting when the result is to build up a compound form with branching and rebranching parts like the limbs of a shrub or tree, and hence giving rise to a kind of structure called arborescent or dendritic; here all the crystals or parts of crystals have their axes in the same direction. The common method of grouping of crystals, however, is quite irregular, and it is only exceptionally that twins or parallel groupings are noted.

Minerals are not always in distinct crystals, like those of garnet or quartz, or even in aggregates of crystals. On the contrary, many of the specimens in a mineral cabinet show no crystalline faces at all, and then they are simply called "massive." There are, however, important distinctions of structure between massive minerals.

First of all, the distinction between "crystalline" and "amorphous" must be well understood. A piece of clear quartz, or rock crystal as it is often called, is said to be crystalline; a piece of glass which very likely the eye alone could not distinguish from it is amorphous or formless. For the mass of quartz, tho it has no definite external form, but is bounded only by irregular fracture surfaces, is just as truly crystalline in structure as a perfect crystal. This is true because the essential idea about a crystallized mineral is that there would be the regular arrangement of the molecules out of which it is built up. It is not always easy, often impossible, with the eye alone to decide whether this regularity of structure exists. It is shown by the cleavage; but when there is no clevage it is usually by optical examination in what is called polarized light that this can be most easily proved. For example, the bright colors given by a thin fragment of a quartz crystal in polarized light shows at once, to one who understands the subject of optics, that it is crystalline in structure. In the glass, on the other hand, the molecules have no definite arrangement at all, and hence no action on polarized light.

The changes of matter which appear in crystallization, distorted and denuded of their grace as they are often found to be, still reveal great laws which never fail, and to which all change is subordinate, and which appear as such to accomplish a gradual advance to lovelier order, and more calmly, yet more deeply, animated Rest. "Nor has this conviction," says John Ruskin in his somewhat fantastic and humanizing yet graceful "Ethics of the Dust," "ever fastened itself upon me more distinctly than during my endeavor to trace the laws which govern the lowly framework of the dust. For, through all the phases of its transition and dissolution, there seems to be a continual effort to raise itself to a higher state; and a measured gain, through the fierce revulsion and slow renewal of the earth's frame, in beauty, and order, and permanence.

"The soft white sediments of the sea draw themselves, in process of time, into smooth knots of sphered symmetry; burned and strained under increase of pressure, they pass into a nascent marble; scorched by fervent heat, they brighten and blanch into the the snowy rock of Paros and Carrara. The dark drift of the inland river, or stagnant slime of inland pool and lake, divides, or resolves itself as it dries, into layers of its several elements; slowly purifying each by the patient withdrawal of it from the anarchy of the mass in which it was mingled. Contracted by increasing drought, till it must shatter into fragments, it infuses continually a finer ichor into the opening veins, and finds in its weakness the first rudiments of a perfect strength. Rent at last, rock from rock, nay, atom from atom, and tormented in lambent fire, it knits, through the fusion, the fibers of a perennial endurance; and, during countless subsequent centuries, declining, or, rather let me say, rising, to repose, finishes the infallible luster of its crystalline beauty, under harmonies of law which are wholly beneficent, because wholly inexorable."

"All crystallization," says the same writer again, "goes on under, and partly records, circumstances of this kind—circumstances of infinite variety, but always involving difficulty, interruption, and change of condition at different times. Observe, first, you have the whole mass of the rock in motion, either contracting itself, and so gradually widening the cracks; or being compressed, and thereby closing them, and crushing their edges; and, if one part of its substance be softer, at the given temperature, than another, probably squeezing that softer substance out into the veins. Then the veins themselves, when the rock leaves them open by its contraction, act with various powers of suction upon its substance; by capillary attraction when they are fine, by that of pure vacuity when they are larger, or by changes in the constitution and condensation of the mixed gases with which they have been originally filled.

"Those gases themselves may be supplied in all variation of volume and power from below; or, slowly, by the decomposition of the rocks themselves; and, at changing temperatures, must exert relatively changing forces of decomposition and combination on the walls of the veins they fill; while water, at every degree of heat and pressure (from beds of everlasting ice, alternate with cliffs of native rock, to volumes of red hot, or white hot, steam), congeals, and drips, and throbs, and thrills, from crag to crag; and breaths from pulse to pulse of foaming or fiery arteries, whose beating is felt through chains of the great islands of the Indian seas, and makes whole kingdoms of the world quiver in daily earthquake, as if they were light as aspen leaves.

"And, remember, the poor little crystals have to live their lives, and mind their own affairs, in the midst of all this, as best they may. They are wonderfully like human creatures—forget all that is going on if they don't see it, however dreadful; and never think what is to happen to-morrow. They are spiteful or loving, and indolent or painstaking, with no thought whatever of the lava or the flood which may break over them any day; and evaporate them into air-bubbles, or wash them into a solution of salts. And you may look at them, once understanding the surrounding conditions of their fate, with an endless interest. You will see crowds of unfortunate little crystals, who have been forced to constitute themselves in a hurry, their dissolving element being fiercely scorched away; you will see them doing their best, bright and numberless, but tiny. Then you will find indulged crystals, who have had centuries to form themselves in, and have changed their mind and ways continually; and have been tired, and taken heart again; and have been sick, and got well again; and thought they would try a different diet, and then thought better of it; and made but a poor use of their advantages, after all.

"And sometimes you may see hypocritical crystals (pseudo-morphs) taking the shape of others, tho they are nothing like in their minds; and vampire crystals eating out the hearts of others; and hermit-crab crystals living in the shells of others; and parasite crystals living on the means of others; and courtier crystals glittering in attendance upon others; and all these, besides the two great companies of war and peace, who ally themselves, resolutely to attack, or resolutely to defend. And for the close, you see the broad shadow and deadly force of inevitable fate, above all this: you see the multitudes of crystals whose time has come; not a set time, as with us, but yet a time, sooner or later, when they all must give up their crystal ghosts—when the strength by which they grew, and the breath given them to breathe, pass away from them; and they fail, and are consumed, and vanish away; and another generation is brought to life, framed out of their ashes."

CHAPTER XV

DESCRIPTIVE MINERALOGY

THERE was a time when there was no life upon the earth, and, therefore, all matter was mineral. This lifeless period extended through untold ages during which no organic substances were formed, and indeed could not have lived. When, however, the earth's surface became fit for organic introduction life appeared, and thenceforward the mineral matter in earth, water and air began to be acted upon by these new agencies, and the living vegetable and animal forms were produced. Life is continually evolving new forms and substance from apparently lifeless matter, endowing it with properties that in the earlier ages it did not possess, yet all life is based upon the mineral.

In addition to the formation of living organisms from matter, it should be noted that these living organisms contain large quantities of such matter, such, for example, as carbonate of lime, the mineral which constitutes the limestones, the chalks and the marbles, making up the shells of the shell-fish and the calcareous covering of the coral polyp; and consequently, just as the animals owe a debt to the rocks, so quite a large portion of the rocks in the earth has been formed from the mineral remains of plants and animals, only again to be recombined into organic life. Thus it may be seen that in the same manner as there is a "geographical cycle," there is also a mineralogical cycle, as the coral polyp takes the mineral calcium from the sea water, and at death returns it to the mineral kingdom. Man is what he is to-day, not only because of the cell-life of his ancestors, but also because of the mineral characteristics of the substances of which they were originally formed.

A mineral has been well defined as a "homogeneous substance of definite chemical composition, found ready-made in nature, and not directly a product of the decay or the life of an organism." It is evident from this definition that the term "mineral" would apply to an enormous variety of substances. However, only those which possess at least a fair economic importance will be treated in the following pages.

One of the best known and at the same time one of the most valuable of minerals is the diamond. In regard to this stone, E. S. Dana, in his "Minerals and How to Study Them," gives the following description: "The diamond is usually found in distinct isolated crystals, most of them very small, but sometimes as large as a robin's egg or even larger. The crystals are commonly octahedrons, though less often some of the other forms of the isometric system are observed. The natural crystals before cutting—"rough diamonds" they are called—frequently have rounded edges and curved faces, or the faces show little pits. The hardness is higher than that of any other species, and the specific gravity is also high, 3.5. The luster is very brilliant; the brilliancy of the diamond, however, is much greater when cut with many facets than in the natural crystals. The most highly priced stones are colorless, but it sometimes occurs as pale yellow, green, pink or blue. The diamond consists of pure carbon, and has thus the same composition as a piece of charcoal. Diamonds are used for cutting glass and, in the form of powder, in grinding diamonds and other hard gems. The black coal-like diamonds, set in a collar and rotated rapidly by machinery, as a diamond drill, cut quickly through the hardest rocks, leaving a core behind, which is raised at intervals; a well-boring is thus easily made.

Graphite, or plumbago as it is often called, is usually found in massive forms which may be separated easily into thin leaves or plates and hence are said to be foliated; sometimes also it is finely granular and compact. It has the same composition as the diamond, consisting also of nearly pure carbon; it is, however, a different substance in its physical characters and is hence a distinct mineral. Note that they differ in crystalline form; also the diamond is hard and heavy, while graphite is soft and light. Graphite is the so-called black lead of the lead-pencils, but it is only like lead in its color. It is an excellent lubricator because of its smooth soapy character when pulverized; also, mixed with clay it is used for making crucibles because it is infusible and not affected by the heat of an ordinary furnace; in electroplating because it is a conductor of electricty. Carbon is also the element which forms the essential part of the different kinds of coal and of mineral oil or petroleum. Anthracite, the coal of eastern Pennsylvania, contains 85 to 95 per cent. of carbon and has a bright shiny surface and conchoidal fracture; it burns with a pale feeble flame without smoke. Bituminous coal is black to dark brown in color, often dull and with a pitchy luster; it contains less carbon than anthracite (usually 75 per cent.) and more hydrogen and oxygen; it burns with a yellow smoky flame. Brown coal, or lignite, has a brown color, dull luster, often retains the structure of the original wood and contains still less carbon, sometimes only 50 per cent. These different kinds of coal and others related to them, tho of great economic value, are not properly mineral species, since they have no definite chemical composition. The same remark applies to asphaltum, bitumen, mineral wax or ozocerite, the many kinds of mineral resins including amber, and finally mineral oil or petroleum, all of which consist chiefly of carbon.

Sulphur is another of the chemical elements occurring in nature. It is found in crystals of the orthorhombic system; a common form is an acute rhombic pyramid. It also occurs in masses and in powder. It is soft and, tho brittle under the blow of a hammer, is easily cut by the knife; the specific gravity is about 2. It has a resinous luster and a bright sulphur-yellow color and streak. The crystals are often clear and transparent. It is used for making sulphur matches; it is one of the three substances of which gunpowder is made (with charcoal and niter); it is used in preparing the rubber gum for overshoes and other purposes; also in making sulphuric acid and in many other ways.

Altho it cannot be preserved in a mineral cabinet, ice, the solid form of water, is as truly a mineral as diamond or quartz. It occurs in crystalline forms of the hexagonal type, often of great complexity and beauty, as seen in snow-crystals. The ice-grains that make the pellets of hail, not infrequently occurring with summer thunder-storms, are also occasionally in clusters of crystals, somewhat resembling the hexagonal pyramids of quartz, tho this is the exception; generally there is simply a concentric concretionary structure. The ice of the pools and ponds is always crystalline, tho it is usually only in the first stages of the process of freezing that the crystals are separately visible.

Arsenic is found occasionally as a mineral and then called Native Arsenic. It has a metallic luster and tin-white color, but soon tarnishes on the surface to a dull dark gray; it is also brittle. It is used with copper and tin to form the alloy called speculum metal, used for metallic mirrors because of the brilliant surface it takes when polished. The lead employed for making shot contains a small amount of arsenic. The compounds of arsenic find various uses, as pigments (sulphite); as a preservative; a poison for insects (white arsenic and Paris green); also in dyeing and medicine.

Antimony, like bismuth, is usually included among the metals, for it has a high metallic luster, altho its structure is crystalline and it is quite brittle. It is a very easily fusible metal and is useful in the arts because of the alloys which it forms with lead and tin, to which it imparts greater hardness and durability. Native Antimony is a bright tin-white mineral with metallic luster, and commonly showing brilliant cleavage surfaces.

Bismuth is silver-white in color with a reddish tinge and has a bright metallic luster; it is rather brittle and shows a crystalline structure with perfect cleavages; it is, however, nearer to the true metals than either arsenic or antimony. Native bismuth is a rare mineral. Some of its alloys have the curious property of contracting instead of expanding with heat. Bismuth is also employed in medicine in the form of the substratum; another compound is used as a cosmetic; other uses are in calico-printing and to give luster to porcelain.

Molybdenite is the sulphide of the rare element molybdenum. Like graphite, which it much resembles, it occurs in foliated masses or in crystalline plates having a hexagonal outline; rarely in distinct hexagonal crystals. It is also very soft, with a soapy feel, and leaves a trace on paper.

Gold is the most highly prized of the metals, valued because it serves as the money of all civilized people, and because of its use for ornaments. It is sometimes found in isometric crystals, as in octahedrons, but usually in plates or scales or wirelike forms; also in larger masses, called nuggets. It is soft and can be cut by the knife. It is highly malleable and ductile and especially remarkable because it can be hammered out into very thin sheets; the skilful gold-beater can make the plates so thin as to transmit a faint greenish light.

Gold occurs mostly in veins in the older crystalline rocks, especially associated with quartz; gold quartz is quartz—often milky—which either shows little particles of gold scattered through it, or from which gold can be obtained—even if not visible to the eye—after the rock is crushed to powder and then washed to remove the lighter material. A large part of the gold of the world has been obtained from the sands and gravels produced by the disintegration of gold-bearing rocks. These gravels in the bed of a stream may be washed by the miner in his pan; or, on a large scale, where a powerful stream of water is thrown against the gravel bank, carrying away the lighter rock and leaving the heavy gold particles behind, usually in the form of little flattened scales.

Platinum is reckoned among the nobler metals with gold, and like it is not attacked by any of the single acids. It has a rather dull gray color, and is not a beautiful metal, altho now more highly valued because of its practical uses than any of the metals except gold. It is rarely found in isometric crystals, as in cubes, more commonly in scales or in larger masses (up to twenty pounds) called nuggets, washed out of the gold sand. The fact that it is fused with great difficulty and is not attacked by ordinary chemical reagents makes it very valuable both to the chemist in the laboratory and in the chemical manufactories, where crucibles and dishes are made of it. It is also largely used by dentists. It has come into use of recent years for the attachments to the ends of the carbon wire in the incandescent electric lamp.

Silver is one of the precious metals, useful alike as money, for ornaments of many kinds, and for utensils. The color is a fine silver-white when perfectly fresh, but it is easily tarnished, and the presence of sulphur in the atmosphere soon turns it black. Native Silver is not an uncommon mineral, altho the world's supply of the metal comes chiefly from its ores. It is like gold in its occurrence, sometimes, tho rarely, in distinct isometric crystals, more frequently in arborescent or branching groups, in plates and scales or wirelike forms; sometimes in fine threads. It is highly malleable and ductile, and is the best known conductor for both heat and electricity.

Mercury is a remarkable metal, because it is a liquid at all ordinary temperatures, only freezing, or becoming solid, at—40°. It has a silver-white color and brilliant metallic luster, and is so mobile that from early times it has been called "quicksilver." Its density is high, 13.6, or higher than silver (10.6) and lead (11.4), and for this reason and because of its liquid form it is of great value for scientific purposes. It is used in most thermometers and barometers, and is employed in many experiments in the physical and chemical laboratories. It also has the property of forming a pasty mass or amalgam with some of the other metals, as gold and silver (also copper, zinc, tin, etc., but not iron), and is hence of great value in separating them from the rock in which they occur. Ordinary mirrors are made of glass backed with amalgam of mercury and tin. Mercury in various forms is also used in medicine, but in minute doses, for it is an active poison. Corrosive sublimate is a chloride of mercury.

Native mercury is a rare mineral in nature, tho occasionally found in minute globules scattered through the rock; the common ore is cinnabar, the sulphide of mercury, sometimes called natural vermilion, which is found in masses of a fine red color, and sometimes also in small rhombohedral or prismatic crystals. The luster is adamantine and the color bright cochineal-red, sometimes becoming dull and dark; the streak is scarlet; crystals are usually perfectly transparent.

Copper is one of the most useful of the metals, having been employed for utensils and in other forms, both as a metal and in different alloys, since very early times. Of recent years its use has been increased very largely because of its good conductivity for electricity. It thus forms the material of the wires of the dynamo machines, those by which the electrical current is carried for the electric light, the trolley, etc. Copper is also extensively used for electroplating, as in making stereotype plates. It forms further a large number of useful alloys, of which brass—an alloy of copper and zinc in the ratio of about 2 : 1—is the best known. In the various kinds of bronze (bell-metal, gun-metal, antique and medal bronze, etc.) copper is also the prominent metal, alloyed with tin; in aluminium bronze it is alloyed with aluminium; in german silver it is alloyed with zinc and nickel. Copper is obtained in nature in the native state, and also from a variety of valuable ores, which are some of the most interesting and beautiful minerals.

"Fool's Gold," Chalcopyrite, or Copper Pyrites, is the beautiful deep brass-yellow copper mineral, often called yellow copper ore. The color is so golden that it is not infrequently mistaken for gold, especially when scattered in small particles through a mass of quartz.

Malachite, the carbonate of copper, is a bright green mineral, often found with native copper, cuprite, and other copper ores because of the readiness with which they are converted into the carbonate by the action of the carbon dioxide present in the air or dissolved in the water. When close and compact it can be cut and polished and thus forms a handsome ornamental stone.

Azurite, or the Blue Carbonate of Copper, is not so common as malachite, but it is also a beautiful mineral, and when in large transparent crystals of a fine deep blue it forms one of the most attractive specimens in a cabinet. The crystals are oblique rhombic prisms.

Lead is one of the most important of the metals, and even pure is used for many purposes familiar to all, as for pipes to convey water and for shot and rifle-balls. It has a dull blue-gray color. It is very soft and malleable. It is often alloyed with other metals; thus with tin in common solder and pewter; with antimony in type-metal; with arsenic in small amount for making shot. White lead (the carbonate) is largely used in making paint, also the oxide, red lead. The supply of the metal, which is used so largely, is obtained from its ores, especially the sulphide, galena. The latter is one of the commonest of minerals, occurring in large deposits in many mining regions. It is also used for glazing common stoneware, and hence it is called potter's ore.

Tin, one of the most important of metals for a great variety of technical purposes, occurs, if at all, only very rarely in nature in the native metallic state. The supply is obtained almost solely from a single ore, the mineral cassiterite, or tin-stone. The use of tin that first suggests itself is for tin plate, so largely employed for vessels, roofing, etc.; this is simply sheet iron coated with metallic tin. Tin enters into many alloys, as the various forms of bronze (gun-metal and bell-metal, etc.), in which it is alloyed with copper; it also forms alloys with lead in pewter and several kinds of solder; with antimony in Britannia metal; with both lead and antimony in Queen's metal, and copper and antimony in Babbitt metal; with lead and bismuth in fusible metal. Cassiterite, or tin-stone, occurs, when crystallized, in square prisms and pyramids and other related forms; twin crystals are common. The crystals have a splendent adamantine luster and a brown color, sometimes nearly black.

Iron may well be called the most important of all the metals. How large a place it takes in the work of the world is shown by the fact that each year some 50,000,000 tons are produced from its various ores and turned into some of the many forms needed by man. The entire supply of iron which the world uses each year is obtained from its ores, in which the iron is in combination chiefly with oxygen. These ores are the minerals hematite, magnetite and limonite; siderite, the carbonate of iron, is also an important ore. The meteorites which occasionally fall to the earth often consist entirely of metallic iron.

Magnetite suggests in its name its most striking character, that of being magnetic. All kinds are strongly attracted by a magnet, and one variety, called the lodestone, found for example at Magnet Cove, Arkansas, is a powerful magnet itself. It has a north and south pole, the power of picking up particles of iron or steel, as tacks, and also, when suspended, it sets with its poles north and south like a compass-needle.

Nickel, tho formerly a little-used metal, has become of much wider application in recent years. It is extensively employed now to plate many articles of steel—as knives, scissors, skates, etc.—because unlike the steel it does not tarnish or rust rapidly in the air. It is much used also, when alloyed with copper, for small coins, as the "nickels" or five-cent pieces of this country, and similarly in Switzerland, Germany and Belgium. Nickel steel has been found to be remarkably strong in withstanding the blow of a cannon-ball. The white alloy called "German silver" contains copper, zinc and nickel in about the proportions of 5 : 3 : 2. There are not, however, many minerals which contain nickel. One of these is the sulphide millerite; another is niccolite, or nickel arsenide.

Cobalt is a metal related to nickel and often associated in nature with it in its various compounds, tho of much more limited occurrence. As a metal it is not used in the arts, but its salts, which are most brightly colored, have some applications. From the change in color that certain of them undergo on heating and on losing water depends their use as sympathetic ink. Cobalt glass, called smalt, has a beautiful blue ultramarine color, and ground up is used as a pigment.

Manganese is a metal which is closely allied to iron in physical characters and chemical relations. As obtained by the chemist—for it does not occur in nature—it is hard and brittle. Like iron, it forms numerous natural compounds, but they do not find many applications in the arts.

Zinc is one of the most common and important of the metallic elements, but it is not certainly known to occur in the form of the metal in nature. It has a crystalline structure like metallic antimony, a white color, and brilliant luster, soon however, tarnishing. It is brittle at both low and high temperatures, but at 140° Centrigrade it can be rolled into sheets.

It is a most important metal in the arts. Iron in sheets and wire, coated by zinc, are protected from rusting, and are then said to be galvanized; a common use of the sheets is for roofing. Zinc is the negative metal in almost all forms of the chemical electric battery—that is, the metal at the expense of which the electric current is obtained. With copper it forms brass and related alloys; it is also one of the constituents in german silver; an alloy of zinc is used for making raised cuts in photo-engraving. The white oxide is used for paint. Metallic zinc, as obtained from the furnace in ingots, is called spelter.

Aluminium is one of the most remarkable of metals, because while it has great tenacity and is in a high degree sonorous and non-oxidizable in the air, it has a specific gravity of less than calcite, or only 2.5. In other words, it is only about one-third as dense as iron and one-fourth as dense as silver, which it somewhat resembles. Both as the pure metal, because of its low density, and in alloys, for example, with copper as aluminium bronze, because of their strength and other remarkable properties, it is highly useful.

Corundum, oxide of aluminium, is, next to diamond, the hardest of minerals and one of great interest. Its clear blue varieties make the sapphire of jewelry, and the clear red the highly prized ruby; while the coarse and impure kinds, when pulverized, are emery, used for grinding. The luster, like that of most very hard minerals, is brilliant and adamantine, tho rather dull in some massive kinds. The color is gray to brown or nearly black in many of the common varieties, called in part adamantine spar; bright blue in the variety called the sapphire; red in the ruby; purple in the Oriental amethyst; yellow in the Oriental topaz.

Turquoise, the beautiful precious stone having the color of robin's-egg blue, also bluish green in less highly prized varieties, is a hydrated phosphate of aluminium, containing also a little copper phosphate, which is probably the source of the color. It occurs only in compact massive forms, filling seams and cavities in a volcanic rock.

Calcium, whose oxide (CaO) is the familiar substance called lime, is a white metal somewhat resembling silver or tin. Its compounds are numerous and important, and it is indeed one of the most widely distributed of all the elements.

Fluorite, or Fluor Spar, Calcium Fluoride, is one of the most beautiful of minerals, occurring in cubic crystals and groups of crystals, sometimes very large and of a great variety of colors, from colorless to green, yellow, brown, red and purple. The crystals are usually transparent, and sometimes show on or near the surface a bright bluish color quite different from that observed when they are looked directly through. The blue light extends within the crystal if it is placed in the direct sunlight. This phenomenon is called fluorescence, and having been first observed with fluorite was named accordingly from it.

Calcite, next to quartz, is the most common of mineral species, remarkable for its variety of form both among the crystallized and uncrystallized varieties. It crystallizes in rhombohedrons and scalenohedrons of great variety and complexity of form, also in hexagonal prisms.

A clear cleavage mass of high-grade calcite, such as that brought from Iceland, is called Iceland spar and is useful for optical prisms. This is because of its remarkable double refraction, or power of dividing a ray of light passing through it into two separate rays, so that a line seen through it appears double.

Besides the crystallized kinds there are those which have a granular structure, as statuary marble, and which sparkle in the light because of the multitude of cleavage-faces. Other kinds are fibrous with a silky luster, like satin spar; also close and compact, as in ordinary marble, and then of great variety of color, red, yellow, blue, black, and largely used for ornamental purposes. Some of these kinds of marble still contain shells, which come out distinctly when polished.

Gypsum occurs in monoclinic crystals; twin crystals are also common. Gypsum also occurs in fibrous forms called, like the similar variety of calcite, satin spar; it is easily distinguished from calcite because so much softer. The luster is pearly on the face of perfect cleavage, otherwise subvitreous; it is also silky in some fibrous forms and in earthy kinds dull. When gypsum is heated and the water of crystallization driven off, Gypsum becomes the anhydrous sulphate. This is done on a large scale and called plaster of paris, which is extensively employed for making plaster casts, for the hard finish for walls, and for other uses. Gypsum is also largely used when ground up for improving soils. The variety alabaster is soft and easily cut into vases and other ornamental objects.

Magnesium is the metal which is present in the oxide (MgO) called magnesia. It is a white metal resembling calcium and closely related to it chemically. In the form of a thin strip or ribbon it burns readily in the air, yielding a very brilliant white light, which is often used as a source of illumination in photography.

Barium is a metal only known in the laboratory, where it can be obtained from some of its compounds. It is a heavy metal, and takes its name from this fact from the Greek word for heavy (βαρύς). All its salts have also high density.

Strontium is the metal which is present in the various salts characterized by the beautiful red color which they give to the flame. The nitrate is thus used in fireworks and red fire; the hydrate is used for preparing and refining beet-sugar and in extracting crystallized sugar from molasses.

The metals sodium and potassium, tho obtained with some difficulty, are interesting to the chemist because they combine so eagerly with oxygen. For this reason they can be preserved only in some non-oxidizable medium, as oil, and a fragment of potassium placed in water takes fire and burns, uniting with the oxygen and liberating hydrogen; sodium also decomposes water.

Halite, or rock-salt (sodium chloride), is one of the few important minerals which is readily soluble in water and hence gives a decided taste. This taste is familiar to every one, for halite is simply the natural form of table-salt. It crystallizes in fine clear cubic crystals with perfect cubic cleavage; it is also found in granular cleavable masses. It has a vitreous luster, and it is colorless when perfectly pure, but from white it passes through various shades of red and yellow; occasional patches of a deep blue are seen in the clear crystals.

Borax, the sodium borate which is so familiar to the housekeeper, also occurs in nature, and on so large a scale in certain limited regions as to be extensively mined. It is found in monoclinic crystals, often of large size; they are clear at first, but lose water on exposure and become white and opaque. Borax finds many uses in the arts, as in making glass and soap, in soldering and in medicine.

Silicon is, next to oxygen, the most widely distributed of the chemical elements; in fact, it is estimated to make up about one-fourth of the earth's crust. The element itself is known only to the chemist, who obtains it with some difficulty from its compounds; one form is that of reddish crystals, resembling those of the diamond and almost as hard. The common compound of silicon in nature is the oxide, SiO_2, called usually simply silica. The well known mineral quartz has this composition. Opal is another kind of silica, amorphous and containing some water.

Quartz, the oxide of silicon, is the commonest of minerals, and in some of its varieties one of the most beautiful. It makes up most of the sand of the seashore; it occurs as a rock in the forms of sandstone and quartzite, and is a prominent part of many other important rocks, as granite and gneiss. It is a mineral which can be usually recognized by its form when crystallized; also by its hardness, conchoidal fracture, its glassy luster and infusibility. The color varies widely; crystals are usually colorless or nearly so, but also yellow and brown to nearly black; there are also pink, green and red kinds. The massive forms vary still more, and the color is often in bands or clouds.

Quartz appears under a great number of varieties, differing particularly in color and structure, and as many have long been used for ornamental purposes, they have received a number of distinct names: Rock-crystal, the clear colorless variety; when quite free from flaws it is used for spectacle-glasses, and the Japanese make crystal spheres of rock-crystal; smoky quartz, having a smoky brown color, sometimes very dark. It is cut into ornaments, and in Scotland it is called cairngorm stone. Amethyst, a fine purple kind, also used for ornaments. A yellow variety of quartz crystal is called false topaz; cat's-eye may be mentioned, giving when polished a peculiar effect of opalescence, due to fibers of asbestos, which somewhat resembles the reflection from the eye of a cat; the same name is given to other stone having like effects; the highly prized cat's-eye of jewelry is a variety of chrysoberyl; chalcedony is a kind having a waxy luster, either transparent or translucent, and varying in color from white to gray, blue, brown, and other shades; agate is a variegated chalcedony, commonly with the colors arranged in delicate parallel bands, straight, curved, or zigzag; onyx is, like much agate, made up of layers of different colors, usually white and black or white and brown, but the banding is straight and the layers are in even planes. The stones may hence be used for cameos, the head being cut from one layer and the background formed by the other; jasper is an impure opaque colored quartz, often red (colored by red iron sesquioxide), also brown or ocher yellow and dark green, sometimes the red and green colors are shown in the same specimen, arranged in bands as in ribbon jasper; and flint, which is nearly opaque and has a dull color, usually gray, smoky brown, and brownish black; it breaks with a deeply conchoidal fracture and a sharp cutting edge, and is hence easily chipped, as by the Indians, into arrow-heads or hatchets.

Opal is a form of silica containing a few per cent. of water. It does not occur in crystals, but in massive and amorphous forms only; these often show a peculiar effect called opalescence, like that of water containing a few drops of milk, and some varieties show a beautiful play of color. The color varies from white to yellow, red, brown, green, gray and black. It is sometimes transparent, but more commonly only translucent. The most beautiful variety of opal is much admired because of the delicate play of colors, due to the optical effect of internal reflections; the colors are often seen on a white, also on a red, ground. One kind of precious opal with a bright red flash of light is called the fire-opal, and another kind is the harlequin-opal. A beautiful opal found in Queensland shows an iridescent blue sometimes like the effect of a peacock's wing.

Infusorial earth is a kind of opal-silica consisting of the microscopic shells of the minute vegetable organisms called diatoms, and as found in beds sometimes of great extent is properly ranked as a mineral and a variety of opal; electro-silicon is the trade name of one kind much used for polishing silver: the siliceous shells are so fine that they do not scratch the surface. A layer of pure white infusorial earth is often found under a peat-bed; it would not be easy to estimate the enormous number of the diatom shells that would be required to make up a cubic inch of it.

Beryl is one of those species which are almost always in distinct crystals and usually in forms easy to recognize; it is also interesting because some varieties are used as a gem. The hardness of beryl is 7.5, or a little above that of quartz, and on this account and because of the beautiful color it sometimes has its rank as one of the precious stones. The luster is vitreous or glassy—in this respect also it resembles quartz—and the color is usually some shade of green: bluish green in common beryl, clear mountain-green in the variety called aquamarine, and a deep emerald-green in the highly prized variety emerald. There are also light or dark yellow kinds sometimes having a rich golden color, and occasionally white and, still more rare, pink kinds.

Garnet is another species which, like beryl, is almost always in distinct crystals, and as these crystals are commonly isolated and scattered through the rock, it is not difficult to recognize them. There are, however, massive kinds needing some skill for their identification; these are occasionally used in the same way as emery, tho much less hard. The luster is vitreous, and the color, while most commonly red, varies also from the colorless kinds to those which are yellow, brown, black, and green.

The micas are characterized before all by their very perfect cleavage, in consequence of which they admit of being split into leaves much thinner than a sheet of paper—in fact, it is difficult to set any limit to the extent to which this process may be carried. These leaves or sheets are usually very elastic and spring back with force when bent. The micas are silicates of alumina with potash, rarely soda or lithia, also magnesia, iron and some other elements.

Chrysolite, or Olivine, is a silicate of magnesia and iron having a vitreous luster and bright yellowish-green color. The luster is vitreous, and the color, besides that mentioned, may be yellow to olive-green and brown. Chrysolite (golden-stone, from χρυσος, gold, and λιθος, stone) is an old term in the mineralogy of former times given to a number of yellow minerals used as gems, thus to beryl, topaz, chrysoberyl and zircon.

Tourmaline is one of the most attractive minerals among the silicates; its varieties show a greater range of color than any other species, not even excepting fluorite, and some of the clear pink and green kinds make beautiful gems. It is almost always found in prismatic crystals, bounded often by three sides, sometimes by six, also by nine, and not infrequently rounded so that there are no distinct faces to be distinguished at all.

Topaz is another gem silicate, beautiful in its fine crystals and in its brilliancy of luster and color. It occurs in prismatic crystals, terminated by rhombic pyramids, sometimes acute, sometimes obtuse. There are also coarse crystals and massive fibrous forms, but these last are not so common. The perfect basal cleavage of topaz is one of its most characteristic points. Hard as it is, it is easily broken in a direction across the prism, and will yield thin plates with very smooth faces.

The luster is vitreous, and the color varies from colorless to white, wine-yellow, and blue. Pink topaz is sometimes found.

Serpentine is a remarkable mineral because of the variety of massive forms it assumes, altho it is not known to occur in crystals of its own. The crystals of serpentine which are found are what are called pseudomorphs, having been derived from some other species by chemical change. The most peculiar variety is the fine fibrous kind called chrysotile (not to be confounded with chrysolite). This usually occurs as thin seams in the massive mineral. Chrysotile may be separated into fibers, very flexible and as soft as the finest silk. This variety is popularly called asbestos, but there is another kind of asbestos of rather similar appearance which is a variety of the mineral amphibole.

These brief descriptions of the principal minerals may serve in some measure to clarify and determine the reader's knowledge of the metals he handles and the stones and rocks whereon he treads, but even so there are fields illimitable of investigation. These might be pointed out in almost any of the minerals, but the question has been so excellently well-worded by Ruskin with regard to marble that it may serve for all. "Another singular point in the business, to my mind," he says, "is that these stones, which men have been cutting into slabs, for thousands of years, to ornament their principal buildings with—and which, under the general name of 'marble,' have been the delight of the eyes, and the wealth of architecture, among all civilized nations—are precisely those on which the signs and brands of these earth agonies have been chiefly struck; and there is not a purple vein nor flaming zone in them, which is not the record of their ancient torture. What a boundless capacity for sleep, and for serene stupidity, there is in the human mind! Fancy reflective beings, who cut and polish stones for three thousand years, for the sake of the pretty stains upon them; and educate themselves to an art at last (such as it is), of imitating these veins by dexterous painting; and never a curious soul of them, all that while, asks 'What painted the rocks?'"

CHAPTER XVI

MINING AND METALLURGY

Among the many minerals which constitute the crust of the earth there are some which are of such character and occur in such quantities that they possess commercial value, and it is profitable to separate them from their neighbors and apply them to the service of mankind. The processes employed in the extraction of these useful minerals are classified under the term "Mining."

The origin of mining retreats into such antiquity as to be most obscure. It is certain, however, that the Phenicians and Egyptians at the earliest periods of history had an abundance of metals. The Egyptians had mines of copper, silver and gold in productive operation both on the Ethiopian and Arabian border. The Sinaitic desert contains the ruins of mining works, probably operated by the Egyptians. Abraham found gold and silver in use among them. In the time of Alexander gold, silver, copper and iron were obtained in Ethiopia. In Asia Minor the gold mines formerly owned by Crœsus were worked down to the time of Xenophon, but Strabo says that in his days they were exhausted. The Athenians worked rich silver mines in Attica and gold mines in Thrace. Before the time of the Romans, mining was carried on in many parts of Western Europe.

After the conquest of Cæsar the tin of Cornwall was shipped first to the Isle of Wight, and thence to the coast of Gaul, where it was loaded upon horses and transported to Marseilles. The early Romans did not work the mines of their native land, but by their numerous conquests gained control of all the important mines of the ancient world. Traces of ancient mining in the United States are found to the copper region of Lake Superior and to certain districts in New Mexico. In both cases the implements used seem to have been rude hammers of stone.

It is evident that in ancient times muscular force, assisted only by applications of fire and occasionally by the power of water, was the miner's resource. A most suggestive picture of rude mining operations is given in the book of Job, xxviii, 1-11, of which Conant's translation brings out the points very strikingly:

> "For there is a vein for the silver, and a place for the gold which they refine. Iron is taken out of the dust, and stone is

> fused into copper. He puts an end to the darkness; and he searches out to the very end, stones of thick darkness and of death-shade. He drives a shaft forgotten of the foot, they swing suspended, far from men! The earth, out of it goes bread; and under it is destroyed as with fire. A place of sapphires, are its stones; and it has clods of gold.—Against the flinty rock he puts forth his hand; he overturns mountains from the base. In the rocks, he cleaves out rivers; and his eye sees every precious thing. He binds up streams that they drip not; and the hidden he brings out to light."
>
> Pliny gives a similar description of shaft-sinking operations:
>
> "Elsewhere pathless rocks are cut away, and are hollowed out to furnish a rest for beams. He who cuts is suspended with ropes. —They go where there is no place for the footprints of man."

The removal of surface material by sluicing was also practiced in ancient times in Spain.

The Aztecs had an extensive metallurgical industry. "They understood how to sink shafts and run tunnels," says John S. Hittell, "how to wash gold from alluvial deposits, how to use the bellows and furnace in smelting the ores of copper, tin, lead and silver, and how to cast metals. They had a little tin and considerable quantities of lead." The Quichuans were not less skilful, and they quarried stone with veins of silver on a large scale. They alloyed gold, silver and tin with copper, so that these metals must have been mined, and a complete knowledge of fluxes in the fusion of ores was known to them. Barbarism generally, which is often regarded as being coupled with the Bronze Age, was obviously possessed of mining, and not only of mining, but of smelting also.

Before proceeding with any further discussion of the useful minerals, it is well to understand what is meant by the expression "ore deposits." This is clearly set forth by Heinrich Ries in his "Economic Geology." "The term ore deposits," he says, "is applied to concentrations of economically valuable metalliferous minerals found in the earth's crust, while under the term "ore" are included those portions of the ore body of which the metallic minerals form a sufficiently large proportion to make their extraction profitable. A metalliferous mineral or rock might therefore not be an ore at the present day, but become so at a later date, because improved methods of treatment or other conditions rendered the extraction of its metallic contents profitable.

"A few metallic minerals serving as ores, such as gold, copper, platinum, or mercury, sometimes occur in a native condition; but in most cases the metal is combined with other elements, forming sulphides, hydrous oxides, carbonates, sulphates, silicates, chlorides, phosphates, or rarer compounds, the first five of these being the most numerous. A deposit may contain the ores of one or several metals, and there may also be several compounds of the same metal present."

The terms "rich" and "poor," as applied to ores, are used with great frequency, altho most indefinite and often meaningless. Under very favorable conditions it is possible to profitably work an ore of given value at one locality, while if found under less favorable conditions at another point it might be almost worthless. The important ore deposits are not numerous. There are many other ores mined for the metal they contain, but they are either of small economic importance or occur in small quantities in nature.

Iron is an abundant constituent of the earth's crust, and yet few minerals are capable of serving as ores of this metal, and five ores supply the greatest amount of the world's iron: Magnetite, Hematite, Limonite, Siderite and Pyrite.

Magnetite occurs in the United States (1) as lenticular masses commonly in metamorphic rocks; (2) as more or less lens-shaped bodies in igneous rocks; (3) as sands on the shores of lakes and seas; and (4) as contact deposits—*i.e.*, those which form along the surface of contact of igneous and sedimentary rocks.

The first class includes the most important deposits now worked in this country. The second and third groups run too high in titanium to have commercial value at the present time, and undoubted representatives of the fourth class of commercial value are not worked. There are some, it is true, which occur along the contact of an intrusive and sedimentary rock, but their origin is ascribed to meteoric circulations.

Of all the iron ores, hematite is by far the most valuable, chiefly on account of its easier reduction, but also because of the greater richness of the known important deposits. Most of the deposits mined belong to the replacement type; that is, they are the result of the replacement of a fissure-filling material.

Limonite may occur under a variety of conditions and associated with different kinds of rocks, but two important types are recognized, viz., bog ores and residual limonites. The bog ores are formed by the precipitation of limonite in swamps, ponds, or lakes. Such ores are usually impure from an admixture of sand or clay which has been deposited at the same time, and are rarely of any thickness. They are of no commercial value in the United States, but are mined more extensively in Sweden and Canada. The residual limonites are a much more important class, and are formed by the weathering of pyritiferous veins or more often from the weathering of ferruginous rocks.

Siderite is the least important of all the ores of iron mined in the United States, both on account of the small quantity and its low iron contents. When of concretionary structure, with clayey impurities, it is termed clay ironstone. Pyrite, tho widely distributed in nature, is not used as an iron because of the large amount of sulphur contained.

Copper-bearing minerals are not only numerous, but widely altho irregularly distributed. More than this, copper is found associated with nearly every variety of ore or ore deposit. Nevertheless, but few minerals serve as ores of copper. All the largest copper deposits in the world may be divided into two groups: (1) Deposits formed by ascending, circulating, probably hot waters, the ores being deposited in fissures, pores, spaces of brecciation, or sometimes replacement of the rock; (2) pod or lens shaped deposits in crystalline schists, which may represent concentration of material from a disseminated condition in the surrounding rocks.

The ores of lead and zinc occur very often associated with each other. Of these Galena is the commonest lead ore, while others are usually found where superficial oxidation of the deposit has taken place. Of the zinc ores sphalerite (also known as blende, jack, or black-jack) is by far the most important. With few exceptions, zinc is constantly associated with lead, and at times, as in portions of the Cordilleran region, carries silver or even gold.

Gold and silver are obtained from a variety of ores, in some of which the gold predominates, in others silver, while in still a third class these two metals may be mixed with the baser metals, lead, copper and zinc. Few gold ores are absolutely free from silver, so that a separate treatment of the two is more or less difficult. Gold occurs in nature chiefly as native gold, mechanically mixed with pyrite, or as a telluride such as calaverite.

Most of the gold and silver mined in the United States is obtained from fissure veins, or closely related deposits of irregular shape, in which the gold and silver ores have been deposited from solution, either in fissures, or other cavities, or by replacement. Considerable gold and a little silver is obtained from gravel deposits. Some true contact deposits are known. Gold has been found to occur in rare instances as an original constituent of igneous rocks and also metamorphic ones, but there are no known deposits of commercial value belonging to this type.

The gold and silver ores are sometimes grouped as (1) Placers or gravel deposits; these serve chiefly as a source of native gold, but may and often do contain a little silver, much of which is never separated from the ore in which it occurs; (2) quartzose or dry ores, in which the gold and some silver are found in a quartz gangue, and are either free or mixed with sulphides, commonly pyrite; (3) gold and silver bearing copper ores; these are widely distributed throughout the United States, and exhibit great differences in form and age, neither do all the occurrences yield much gold or silver; (4) gold and silver bearing lead ores; this class includes a variety of deposits, containing much lead, and also silver, with gold usually in subordinate amounts.

Since gold and silver ores so vary in their mineralogical associations and richness, the metallurgical processes involved in their extraction are varied and often complex. Those ores whose precious metal contents can be readily extracted after crushing, by amalgamation with quicksilver, are termed "free-milling ores." This includes the ores which carry native gold or silver, and often represent the oxidized portions of ore bodies. Others, containing the gold as telluride or containing sulphides of the metals, are known as "refractory ores" and require more complex treatment. These, after mining, are sent direct to the smelter if sufficiently rich, but if not they are often crushed and mechanically concentrated. The smelting process is also used for mixed ores, the latter being often smelted primarily for their lead or copper contents, from which the gold or silver is then separated.

Low-grade ores may first be roasted, and the gold then extracted by leaching with cyanide or chlorine solutions. The introduction of the cyanide and chlorination processes, which are applied chiefly to gold ores, has permitted the working of many deposits formerly looked upon as worthless, and in some regions even the mine dumps are now being worked over for their gold contents.

The Silver-Lead Ores form a large class, which are widely distributed in the Cordilleran region, and not only supply most of the lead mined in the United States, but in addition may also and often do carry variable quantities of silver, gold and copper. The deposits as a whole present a variety of forms. The associated rocks are often faulted, and the ore bodies are commonly oxidized above so that the altered portions require different metallurgical treatment from the sulphide ores found below. Secondary enrichment has in some cases raised the grade of the ore.

Aluminium is one of the few metals whose ores do not present a metallic appearance. Many different minerals contain aluminium, but it can be profitably extracted from only a few. Common clay, for example, presents an inexhaustible supply, but the chemical combination of the aluminium in it is such that its extraction up to the present time has not been found practicable.

While many different minerals contain manganese, practically the only ones of commercial value are the oxides and carbonates, and in this country only the former. The silicates are not used as a source of manganese, owing to their high silica percentage. The several ores of manganese are often intimately associated, the pyrolusite generally assuming a crystalline and the psilomelane a massive character. Manganese oxides are also often intermixed with more or less oxide of iron, and considerable amounts of the metal are obtained from manganiferous zinc, silver or iron ores. Since much manganese is used in iron reduction, the last association is of importance.

Mercury ores are not confined to any particular formation, but are found in rocks ranging from the Ordovician to Recent Age in different parts of the world. Nor are they peculiar to any special type of rock, altho igneous rocks are often found in the vicinity of them. They occur as veins, disseminations, or as masses of irregular form.

The most important ore of antimony is Stibnite, and the metal is rarely obtained from any other mineral, altho native antimony has been sparingly found. The stibnite, together with a gangue of quartz, and sometimes calcite, usually forms veins cutting igneous, sedimentary, or metamorphic rocks. Antimony has been found at a number of localities in the Cordilleran region, but the great distance of the deposits from the railroads, together with the fact that the smelting plants are located in the East, make them of little commercial value, and no domestic production has been reported since 1901. Moreover, the large output of antimony ores and metal abroad, combined with low ocean freights and the absence of any import tax on crude antimony, are of themselves discouraging to domestic competition.

Nickel and Cobalt can best be treated together, for nearly all the ores containing one are apt to carry some of the other, and furthermore, in smelting, the two metals go into the same matte, and are separated later in the refining process. The nickeliferous Pyrrhotite is the most widely distributed of the nickel ores, and may carry small amounts of cobalt. It is also called Magnetic Pyrites. The percentage of nickel ranges from a trace to 6 per cent., but an increase above this brings it into Pentlandite.

The ores of Platinum are native platinum and sperrylite. The former is commonly found in placer deposits, but it has also been noted in basic igneous rocks rich in olivine, such as peridotite, or in serpentine derived from it. The sperrylite never occurs in large quantities, but has been found in association with nickel and copper ores. Iridosmine and osmiridium are also known to carry platinum. The nuggets found in placers are often regarded as being pure native platinum; this is only partly true.

The chief ore of Tin is Cassiterite, with 78.6 per cent. metallic tin, but owing to the presence of impurities the ore rarely shows this composition. Its hardness, imperfect cleavage, nonmagnetic character, high specific gravity and brittleness help to distinguish it from other minerals that are liable to occur with it. Stream tin is the name applied to cassiterite found in placers.

Metallurgy is defined as the art of extracting metals from their ores and adapting them to the various processes of manufacture. That this art was practiced in very early times is indicated by reference to the use of metals in the oldest written records of the world's history. Among the many stages in the development of primeval man none can have been of greater moment in his struggle for existence than the discovery of the metals and the means of working them. The names generally given to the three prehistoric periods of man's life on earth —the Stone, the Bronze and the Iron Age—imply the vast importance of the progressive steps from the flint knife to the bronze celt and, lastly, to the keen-edged steel weapon or tool.

The metals chiefly used have been gold, silver, copper and tin (the last two forming the alloy called bronze), iron and lead. Of all metallurgical processes, that of the separating of lead from its ores is the oldest. Lead smelting was known to the ancient Hebrews, and silver ornaments were found on the site of ancient Troy that were so pure as to show that the Trojans knew how to separate silver from lead. Lead ores were wrought by the ancient Egyptians perhaps 3,000 years B.C.

The value of iron in ancient times is well brought out by the fact that in Homer's Iliad a mass of iron is mentioned as being one of the prizes at the funeral games of Patroclus.

Metallurgical processes of the present day may be divided into mechanical and chemical. Under mechanical are included the various processes of ore dressing or concentration, the object of which is to separate nearly pure mineral from what is of little or no value.

The methods of extracting metals directly from the crude ore or from the mechanically separated concentrates fall under three classes: (1) Extraction of the metal from oxides and carbonates by the reducing action of carbon and the treatment of sulphides by the oxidation of the sulphur contained; (2) the extraction of a metal by getting it in solution and replacing it by another; (3) amalgamation, or bringing the metal in contact with quicksilver, with which it forms an amalgam. Most metals are obtained ultimately by the use of heat, either by treating the crude ore or the concentrates obtained by some method of ore dressing.

It is well, however, before beginning a discussion of the metallurgy of iron and steel to define just what is the iron and steel of commerce and industry.

In Henry Marion Howe's Iron, Steel and Other Alloys they are described as "composite or granitic substances, intimate mechanical mixtures or conglomerates of microscopic particles of certain quite distinct, well-defined simple substances in widely varying proportions."

The chief of these substances are—

Ferrite, the microscopic particles of nearly and perhaps perfectly pure metallic iron. It is magnetic, very soft and ductile, but relatively weak, with a tensile strength of about 45,000 pounds per square inch. It is of the isometric system. It always forms a very important part of slowly cooled iron and steel in general.

Cementite, a definite carbide of iron, Fe_3C, containing 6.67 per cent. of carbon, very brittle, harder than hardened steel, scratching glass and feldspar but not quartz, and magnetic. The carbon in slowly cooled steel is chiefly or wholly present as cementite.

Graphite, a characteristic component of "gray cast iron," of which it usually forms from 2 to 3.50 per cent. It is pure or nearly pure carbon. When it forms during the solidification of the metal, as is usually the case, it occurs in very thin laminated plates or flakes, often ⅛ inch or more in diameter. When it forms within the solid metal at temperatures materially below the freezing-point, it occurs, at least under certain conditions, in very fine powder and is then called "temper" graphite, the temper-carbon of Ledebur.

Slag, the characteristic component of wrought iron, which usually contains from 0.20 to 2 per cent. of it. It is essentially a ferrous silicate and is present in wrought iron simply because this variety of iron is made by welding together pasty granules of iron in a bath of such slag, without subsequently melting the resultant mass or in any other way giving the envelopes of slag thus imprisoned a chance to escape completely.

The great classes of iron and steel of chief value to the engineer and probably to the world at large are essentially intimate mixtures or conglomerates of the first two strikingly different microscopic constituents, ferrite extremely soft and ductile, cementite extremely hard and brittle, the former like copper, the latter like glass. The properties of several of the classes may indeed be influenced, and very profoundly, by thermal and mechanical treatment and by the presence in certain of them of slag or of graphite; but the fact on which our attention should be concentrated at first is this, that the difference in properties between the different industrial classes of iron and steel are due chiefly to differences in the ratio which the ferrite bears to the cementite.

What has just been said does not apply, it is true, to what is called "hardened steel," but it does apply to the great industrial classes of wrought iron and of steel such as ship, rivet, fencing-wire, tube, rail and tin-plate steel and indeed all structural steels, whether for plates, beams, eyebars, angle-irons or any like object.

The steels which are especially soft and ductile—*e.g.,* the rivet and boiler-plate steels—consist chiefly of the soft, ductile, copper-like ferrite, as do those with very high electric conductivity, such as telegraph and telephone wires. In these steels the proportion of cementite may not exceed 1 per cent. of the whole, the rest consisting almost wholly of ferrite.

The harder steels like rail steels, which are called upon to resist abrasion—*e.g.,* the grinding action of the car-wheels intensified by the presence of sand between wheel and rail—have a much larger proportion of cementite. About 93 per cent. of their total mass is made up of ferrite and the remaining 7 per cent. consists of cementite. This quantity of cementite suffices to increase greatly the resistance to abrasion, while the loss of ductility which it causes, tho very marked, is not dangerously great.

Naturally as the proportion of cementite in steel increases and that of ferrite decreases, the ductility diminishes continuously and the hardness increases continuously; the tensile strength, however, reaches a maximum when the cementite amounts to about 15 per cent. of the whole and the ferrite is about 85 per cent.; with further increase of cementite the tensile strength again decreases.

The constitution of steel is not in general reported in the percentages of ferrite and cementite, nor, indeed, are most engineers and metallurgists of to-day sufficiently familiar with this aspect of the subject to speak of it with confidence. But this is the aspect which the practitioners of the near future must face, and it is also that which makes possible an understanding of the relation between the composition and properties of these different classes of iron and steel. Instead of saying that a certain kind of steel, for instance rail steel, contains so much cementite and so much ferrite, it is customary to report simply the carbon which that cementite represents.

Graphite is an important constituent of cast iron, especially of gray cast iron, but may be regarded as either absent from steel or, if present, only in unimportant quantities.

Gray cast iron, the only kind of cast iron which can be widely used by engineers, may be regarded as a conglomerate of the second degree, for it consists first of a mechanical mixture of ferrite with cementite quite as steel does, while through this mixture as a matrix there is scattered much free carbon in the form of sheets of graphite.

White cast iron typically would consist of cementite and ferrite quite as structural steel does, but with a much larger proportion of cementite, rising even to 67 per cent. (say 4.50 per cent. of carbon). Hence the extreme hardness and brittleness of this class of cast iron, so extreme as to exclude it from most engineering uses.

Wrought iron consists essentially of a metallic matrix identical with low-carbon steel, in which is mechanically mixed a small quantity of slag, a silicate of iron; this slag is not unimportant, yet it is far less important than the ferrite and cementite of the matrix.

Steel hardened by sudden cooling from a red heat consists essentially of austenite, a solid solution of carbon in iron of varying degrees of concentration. When austenite contains as much as 1 per cent. of carbon it is intensely hard and brittle, and indeed its hardness and brittleness are roughly proportional to the quantity of carbon which it contains. Hence steels for purposes which require extreme hardness, such as files and other tools for cutting metals and even wood, have from about 0.75 to 2 per cent. of carbon, enough to give the degree of hardness required for the special purpose, but not enough to cause a prohibitory degree of brittleness, and they are "hardened" by sudden cooling. Besides the cutting tools, armor-plate and projectiles are made of hardened steel and therefore consist essentially of austenite.

Alloy steels have come into extensive use for important special purposes and a very great increase of their use is to be expected. The chief ones are nickel steel, manganese steel, chrome steel, molybdenum steel and tungsten steel. The general order of merit of a given variety or specimen of iron or steel may be measured by the degree to which it combines strength and hardness with ductility.

Nickel steel, which endures well the effect of sudden shock, is used widely for marine shafting. It has been used tentatively for railroad rails, but while it has the stiffness and resistance to wear which they require, too many rails have broken in use.

As actually made, manganese steel contains about 12 per cent. of manganese and 1.50 per cent. of carbon. Its ductility, to which it owes much of its value, is profoundly affected by the rate of cooling. Sudden cooling makes the metal extremely ductile and slow cooling makes it brittle; its behavior in this respect is thus the opposite of that of carbon steel. Its great hardness, however, is not materially affected by the rate of cooling. It is used extensively for objects which require both hardness and ductility, such as rock-crushing machinery, railway crossings, mine-car wheels and safes.

Chrome steel, which usually contains about 2 per cent. of chromium and 0.8 to 2 per cent. of carbon, owes its value to combining, when in the "hardened" or suddenly cooled state, intense hardness with a high elastic limit, so that it is neither deformed permanently nor cracked by extremely violent shocks. For this reason it is the material generally if not always used for armor-piercing projectiles.

Tungsten steel, which usually contains from 5 to 10 (and sometimes even 24) per cent. of tungsten and from 0.4 to 2 per cent. of carbon, is used for magnets, because of its great retentivity, and for lathe and similar metal-cutting tools which are to cut off a very thick slice at each stroke. The great friction, due to the thickness of the cut, heats the tool to a temperature at which the temper of common or "carbon" steel is drawn. The merit of tungsten steel is that, like manganese steel, it retains its extreme hardness, even after it has been heated to 400° C. (752° F.). Under these conditions the Taylor and White variety retains its cutting power even when the friction is so great that the chips of metal cut are so hot as to glow visibly, and even the edge of the tool itself grows red hot.

Molybdenum Steel is now often used instead of tungsten, 1 per cent. of the former element replacing 2 per cent. of the latter, so that the ratio between their effects appears to be that which their atomic weights would indicate as probable. In other words, one molecule of molybdenum appears to have the same effect as one molecule of tungsten.

To-day practically all of the iron ore mined is smelted in the iron blast-furnace and there converted into cast of pig iron; and this is the case whether the resultant iron is to be used in the form of cast iron or whether it is to be converted into one of the two other great commercial classes of iron, wrought iron and steel. It is true that there are many direct processes by which wrought iron or steel may be made directly from the ore without first converting it into cast iron—*i.e.*, without first putting into it more carbon and silicon than it needs in its finished form and then taking them out at great expense. But these processes are to-day of little more than historical or scientific interest. Whatever promise they may have had in recent decades has been killed by the great cheapening of the blast-furnace process.

The Blast-furnace is an enormous shaft, in many cases as much as 100 feet high and 25 feet maximum inside diameter. The furnace is at all times full from top to bottom of a column consisting of coke or other fuel, limestone and iron ore, tho the lower part of this column consists of fuel only. The ore, flux and fuel are charged through a hopper at the top of the furnace and form a continuous column extending from the top to the bottom. Through openings called tuyeres at the bottom of the furnace a powerful blast of air, usually highly preheated, is introduced; this burns the fuel, thereby generating an intensely high temperature, sufficient to melt the ore, the iron of which has, by the time it has descended to this region, become reduced to the metallic state. Thus the whole column of solid materials descends slowly as its lower end is eaten away, the fuel which it contains being burned away by the blast and the rest of the material being melted away by the heat from the combustion of this fuel.

In addition to the descending column of solid material there is an ascending column of hot gases. The oxygen of the blast introduced at the tuyeres is quickly converted into carbonic oxide by its reaction with the carbon of the fuel which it there meets.

Very soon after entering the furnace through the tuyeres the atmospheric oxygen has been converted into carbonic oxide, which, together with the atmospheric nitrogen of the blast, sweeps up through the furnace in enormous columns at great velocity. There is thus two columns moving in opposite directions: a solid column of ore, flux and fuel descending very slowly and a swiftly rising column of hot gases. Any given lump of the solid material passes through the furnace in about 12 to 15 hours, while any given particle of oxygen or nitrogen entering at the tuyeres passes through and quickly escapes at the top, its passage occupying probably only a small fraction of a minute.

The iron ore always contains besides iron oxide a considerable quantity of silicious or earthy material called gangue, and the fuel also contains a certain amount of ash. These materials, the gangue and the ash together with the lime of the limestone, unite to form a single molten mass, the slag, which floats on top of the molten iron. Two deep holes are provided at the lower end of the furnace, one, called the tap-hole, at its very bottom for drawing off the molten iron at intervals, and the other, called the "cinder-notch," a very little above this, for drawing off the molten slag. These holes are closed with plugs of clay, except at the time when the molten materials are drawn through them.

While these two columns, the descending solids and the ascending gases, pass each other, and the hot gas is sweeping up swiftly, the the initially cold, solid materials descending slowly, the heat of the gaseous column is recovered by being transferred to the descending solids, so that altho the temperature of the gases in the neighborhood of the tuyeres is above 2,912° F., the temperature of those which escape from the top of the furnace is only about 572° F. to 752° F. Owing to the fact that the fuel is burned in immediate contact with the solid materials which it is to heat, and that the products of its combustion are thoroly cooled in their long upward travel in which they are exposed to cooler and cooler masses of descending solid materials, the thermal efficiency of the blast-furnace is very high.

The purifying reactions are brought about (1) in the puddling process by stirring iron oxide (in the form of a silicate very rich in that oxide) into the molten cast iron as it lies in a thin boiling layer on the hearth of a reverberatory furnace; (2) in the Bessemer process by blowing cold atmospheric air through the molten cast iron in a deep clay-lined or dolomite-lined retort called a converter, the rapidity of the oxidation itself raising the temperature rapidly; and (3) in the open-hearth process by exposing the molten cast iron in a thin and very broad layer on the bottom of a reverberatory furnace to an overlying layer of slag containing iron oxide, and usually enriched in that oxide by throwing into it lumps of iron ore. In this last process, in addition to this purification of the cast iron by these oxidizing reactions, its impurities are in most cases also greatly diluted by adding much relatively pure steel scrap.

If steel is cooled suddenly it is thereby made harder and less ductile or even extremely brittle and is said to be "hardened." The degree to which it is thus hardened increases with the carbon-content, so that whereas very low-carbon steel is affected only very slightly, steel with 1 per cent. of carbon is made as hard and nearly as brittle as glass.

The hardness and brittleness induced increase with the rapidity of cooling without limit, but they are apparently nearly independent of the temperature from which the sudden cooling begins.

The tensile strength at first increases with the intensity of hardening, but reaches a maximum and then declines. In case of high-carbon steel a moderate rapidity of cooling may give the highest tensile strength, but in case of low-carbon steel the tensile strength seems to increase with rapidity of cooling without limit.

Hardened steel is "tempered"—*i.e.,* the hardening is mitigated or let down, by slight reheating, say to 200° or 300°—and the steel is "annealed"—*i.e.,* the hardening is completely removed, by reheating farther, say to 600°. After this reheating to 200° or 300° it is immaterial whether the steel is then cooled suddenly or slowly; the degree of tempering is the same in either case, and the same is substantially true of the higher heating to 600°, or annealing.

All the best cutlery and tool steel is made by the crucible process, and indeed all for which any considerable excellence is claimed is supposed to be, tho often incorrectly. But the great mass of the steel of commerce is made by the Bessemer and the open-hearth processes, the latter being generally considered the best, and rising from 9 to 53 per cent in the United States, it reveals in a wonderfully true proportion the advance of progress.

BIOLOGY

BIOLOGY

CHAPTER I

BIOLOGY: THE SCIENCE OF LIFE

LIFE, that strange, mysterious, unknown something which flies through the viewless air, flashes through the ocean's depths, blushes in the petals of a rose and manifests itself in a thousand marvelous forms —can science grasp, define or explain it? Death, that wondrous change which sooner or later stills the activities of all forms of life and returns them to the realm of the lifeless—what is its nature? Why is it necessary? Can science understand or control it? These inquiries and others like them which have troubled the human mind in all ages are the fundamental problems of the science of life.

With the dawn of human consciousness there must have come the realization that this is an earth with two worlds—the living and the lifeless. The progress of the ages has not lessened the contrast; and to-day, men of science, recognizing the great chasm between life and death, between the living and the lifeless on the earth, are compelled to group the natural sciences into the Biological Sciences dealing with living things or organisms; and the Abiological Sciences, or Physical Sciences, dealing with lifeless matter. The biological sciences are known collectively as biology, which is therefore often defined as the science of life, of living things, or of living matter. "But living matter," says Sedgwick and Wilson in their "General Biology," "is only ordinary matter which has entered into a peculiar state or condition. And hence biology is more precisely defined as the science which treats of matter in the living state."

If the term biology be used in its widest sense of Life-lore to include all the results of the scientific study of living creatures, it may be said to have had its foundations in antiquity. But if the term is restricted to the use as defined above—that is, to the study of the vital phenomena common to both plants and animals—it is quite modern.

Biology is not a new name for the older science known as Natural History, nor is it, as is often thought, a combination of botany and zoology, it is rather a unified science of life. Taken in this sense, the science has been in existence but little more than a hundred years. The history of its development is the history of the splitting up of the Natural History of earlier times into the separate sciences known today, physics, chemistry, botany, zoology, etc.; a recognition of the essential similarity of the vital functions of all living things, plants or animals; and the development of a separate science for the study of these phenomena. Huxley, in his essay "On the Study of Biology," writes of its history in these words:

"At the revival of learning, knowledge was divided into two kinds—the knowledge of nature and the knowledge of man; for it was the current idea then—and a great deal of that ancient conception still remains—that there was a sort of essential antithesis, not to say antagonism, between nature and man; and that the two had not very much to do with one another, except that the one was oftentimes exceedingly troublesome to the other. Tho it is one of the salient merits of our great philosophers of the seventeenth century, that they recognized but one scientific method, applicable alike to man and to nature, we find this notion of the existence of a broad distinction between nature and man in the writings both of Francis Bacon and of Thomas Hobbes. Hobbes says: "The register of knowledge of fact is called history. Whereof there be two sorts, one called natural history; which is the history of such facts or effects of nature as have no dependence on man's will, such as are the histories of metals, plants, animals, regions and the like. The other is civil history; which is the history of the voluntary actions of men in commonwealths."

Thus all history of fact was divided into these two great groups of natural and of civil history. As time went on, and the various branches of human knowledge became more distinctly developed and separated from one another, it was found that some were much more susceptible of precise mathematical treatment than others. The publication of the "Principia" of Newton showed that precise mathematical methods were applicable to those branches of science such as astronomy, and what is now called physics, which occupy a very large portion of the domain of what the older writers understood by natural history.

Time went on, and yet other branches of science developed themselves. Chemistry took a definite shape; and since all these sciences, such as astronomy, natural philosophy and chemistry, were susceptible either of mathematical treatment or of experimental treatment, or of both, a broad distinction was drawn between the experimental branches of what had previously been called natural history and the observational branches—those in which experiment was (or seemed) of doubtful use, and where, at that time, mathematical methods were inapplicable.

Under these circumstances the old name of "Natural History" stuck by the residuum of those phenomena which were not, at that time, susceptible of mathematical or experimental treatment; that is to say, those phenomena of nature which come now under the general heads of physical geography, geology, mineralogy, the history of plants, and the history of animals. It was in this sense that the term was understood by the great writers of the middle of the last century, Buffon and Linnaeus, by Buffon in his great work, the "Histoire Naturelle Générale," and by Linnaeus in his splendid achievement, the "Systema Naturae." The subjects they deal with are spoken of as "Natural History," and they called themselves and were called "Naturalists." It is clear that such was not the original meaning of these terms; but that they had by this time, acquired a signification widely different from that which they possessed primitively

Despite the marvelous progress made by science at the latter end of the eighteenth and the beginning of the nineteenth century, thinking men began to discern that under this title of "Natural History" there were included very heterogeneous constituents. For example, it was not hard to see that geology and mineralogy were, in many respects, widely different from botany and zoology; that a man might obtain an extensive knowledge of the structure and functions of plants and animals without having need to enter upon the study of geology or mineralogy, and vice versa; and, further as knowledge advanced, it became clearer that there was a great analogy, a very close alliance, between those two sciences, of botany and zoology, which deal with living beings, while they are much more widely separated from all other studies. Therefore, it is not wonderful that, at the beginning of the nineteenth century, in two different countries, and apparently without any intercommunication, two famous men clearly conceived the notion of uniting the sciences which deal with living matter into one whole, and of dealing with them as one discipline.

In fact, there were three men to whom this idea occurred contemporaneously, altho but two who carried it into effect, and only one who worked it out completely. These persons were the eminent physiologist Bichat; the great naturalist Lamarck, in France, and a distinguished German, Treviranus. Bichat assumed the existence of a special group of "physiological" sciences. Lamarck, in a work published in 1801, for the first time made use of the name "Biologie," from the two Greek words which signify a discourse upon life and living things. About the same time it occurred to Treviranus, that all those sciences which deal with living matter were essentially and fundamentally one, and ought to be treated as a whole; and, in the year 1802, he published the first volume of what he also called "Biologie." Treviranus's great merit lies in this, that he carried out his idea, and wrote the very remarkable work above mentioned. It consists of six volumes, and occupied its author for twenty years—from 1802 to 1822. That is the origin of the term "Biology," which denotes the whole of the sciences which deal with living things, whether they be animals or whether they be plants.

After discussing the origin of the science of biology, the next questions that naturally present themselves are with reference to the extent and nature of its scope. In its strict technical sense, Biology denotes all the phenomena which are exhibited by living things, as distinguished from those which are not living; but while that secondary definition suffices in the domain of the lower animals and plants, it is found to involve considerable difficulties in an investigation of the higher forms of living things. For whatever views may be entertained about the nature of man, one thing is perfectly certain, that he is to be considered a living creature. Hence, a strict interpretation of such a definition must include man and all his ways and works under the head of biology; in which case, psychology, politics, and political economy would be absorbed into the province of Biology.

It has been found convenient to set human psychology and sociology apart from biology, but the progress of these sciences in the past century has clearly shown that they are intrinsically inseparable from biology or that they at least find many of their fundamental principles in the general science of life.

Even without the psychological and sociological phases of human life, the field covered by biology as thus understood is so wide as to necessitate a subdivision of the subject into a number of branches, to which are usually assigned the rank of distinct sciences. As already pointed out, the usual division of biology into botany and zoology has the great advantage of practical convenience, since, as a matter of fact, most biologists devote their attention mainly either to plants alone, or to animals alone. From a scientific point of view, however, a better subdivision is into Morphology and Physiology. The former is based upon the facts of form, structure and arrangement, and is essentially statical; the latter upon those of action or function, and is essentially dynamical. But morphology and physiology are so intimately related that it is impossible to separate either subject absolutely from the other, for which reason authors speak of plant morphology and animal morphology, plant physiology and animal physiology.

There are further subdivisions. Thus on the plant or animal side of biology there are the following subsciences: Anatomy—the science of structure, the term being usually applied to the coarser and more obvious composition of plants or animals; Histology—microscopical anatomy, the ultimate analysis of structure by the aid of the microscope, separated from anatomy only as a matter of convenience; Taxonomy—the classification of living things, based chiefly on the phenomena of structure; Distribution—considering the position of living things in space and time, their distribution over the present face of the earth and their distribution and succession at former periods, as displayed in fossil remains; Embryology—the science of development from the germ, including many problems pertaining both to morphology and physiology; and Physiology (including pathology)—the special science of the functions of the individual in health and in disease. The very highly specialized biological sciences, ornithology (birds), entomology (insects), herpetology (reptiles), conchology (shells), lichenology (lichens), bryology (mosses), mycology (fungi), etc., apply to the groups of animals and plants indicated by the names of these sciences. They are chiefly concerned with classification and hence deal largely with details of structure.

While the scope of biology may be thus skeletonized, it must be pointed out with emphasis that the common conception of biology as simply a combination of botany and zoology is one which tho convenient and indeed necessary for practical purposes, and for extended study and research, does not concern the present treatment. Dealing with organic structures and functions in connection with their causes, conditions, concomitants and consequences, Biology cannot divide itself into Animal Biology and Vegetable Biology; since the same fundamental classes of phenomena are common to both. It is with these general vital phenomena common to both plants and animals that this work is concerned, hence in considering the general problems of the science of biology the familiar division into botany and zoology is recognized only occasionally as a matter of convenience. Undoubtedly confusion will be avoided if it is kept in mind that "General Biology" is the subject under view. This term does not designate a particular member of the group of biological sciences, "but is only a convenient phrase, which has recently come into use for the general introductory study of biology. It includes a description of the general properties of living matter as revealed in the structures and actions of living things, and may serve as the basis for subsequent study of more special branches of the science. It deals with the broad characteristic phenomena and laws of life as they are illustrated by the thoro comparative study of a series of plants and animals taken as representative types; but inasmuch as all the varied phenomena which come under observation are in the last analysis due to the properties of matter in the living state, the biologist ever remembers that this matter and these properties are the goal of study."

CHAPTER II

WHAT IS LIFE?

More puzzling than the riddle propounded by the fabled Sphinx is the problem suggested by the title of this chapter. "What is life?" is a question which has been asked by the scholars of all ages and man to-day is no nearer a final answer than were the philosophers in the earliest centuries of the historic era. Modern science has vastly extended knowledge of the phenomena which are called vital but has failed to tell what life is. Thus according to Herbert Spencer's so-called proximate definition, which of the many definitions of life has attracted most attention, life is the continuous adjustment of internal relations to external relations. This definition Spencer has explained as follows:

"All vital actions, considered not separately but in their ensemble, have for their final purpose the balancing of certain outer processes by certain inner processes. There are unceasing external forces tending to bring the matter of which organic bodies consist, into that state of stable equilibrium displayed by inorganic bodies; there are internal forces by which this tendency is constantly antagonized, and the perpetual changes which constitute Life may be regarded as incidental to the maintenance of the antagonism. To preserve the erect posture, for instance, we see that certain weights have to be neutralized by certain strains: each limb or other organ, gravitating to the Earth and pulling down the parts to which it is attached, has to be preserved in position by the tension of sundry muscles; or in other words, the group of forces which would if allowed bring the body to the ground, has to be counterbalanced by another group of forces. Again, to keep up the temperature at a particular point, the external process of radiation and absorption of heat by the surrounding medium, must be met by a corresponding internal process of chemical combination, whereby more heat may be evolved; to which add, that if from atmospheric changes the loss becomes greater or less, the production must become greater or less. And similarly throughout the organic actions in general.

"When we contemplate the lower kinds of life, we see that the correspondences thus maintained are direct and simple; as in a plant, the vitality of which mainly consists in osmotic and chemical actions responding to the coexistence of light, heat, water and carbonic acid around it. But in animals, and especially in the higher orders of them, the correspondences become extremely complex. Materials for growth and repair not being, like those which plants require, everywhere present, but being widely dispersed and under special forms, have to be found, to be secured, and to be reduced to a fit state for assimilation. Hence the need for locomotion; hence the need for the senses; hence the need for prehensile and destructive appliances; hence the need for an elaborate digestive apparatus.

"Observe, however, that these successive complications are essentially nothing but aids to the maintenance of the organic balance in its integrity, in opposition to those physical, chemical and other agencies which tend to overturn it. And observe, moreover, that while these successive complications subserve this fundamental adaptation of inner to outer actions, they are themselves nothing else but further adaptations of inner to outer actions. For what are those movements by which a predatory creature pursues its prey, or by which its prey seeks to escape, but certain changes in the organism fitted to meet certain changes in its environment? What is that compound operation which constitutes the perception of a piece of food, but a particular correlation of nervous modifications, answering to a particular correlation of physical properties? What is that process by which food when swallowed is reduced to a fit form for assimilation, but a set of mechanical and chemical actions which distinguish the food? Whence it becomes manifest, that while Life in its simplest form is the correspondence of certain inner physico-chemical actions with certain outer physico-chemical actions, each advance to a higher form of life consists in a better preservation of this primary correspondence by the establishment of other correspondences.

"Divesting this conception of all superfluities and reducing it to its most abstract shape, we see that Life is definable as the continuous adjustment of internal relations to external relations."

It is clear that this definition in the last analysis is but a general statement of the fundamental vital relations existing between living matter and lifeless phenomena. It does not really define life. Other authors have done no better, in fact their definitions have been less inclusive. But aside from attempts at forming abstract definitions of life there are some significant considerations regarding living matter which have been important in the development of knowledge of the differences between the living and the lifeless and of the working of the mechanism of life.

The living and the lifeless present a fundamental contrast. "If the development of the conception of life be followed back," says Verworn, "when mankind had no presentiments of all the occupations that accompany a highly developed culture, when he was unacquainted with fire, when he did not know how to make even the most primitive tools, the conclusion is reached that the conception sprang from the combination of a number of simple phenomena, which early man discovered by self-observation, especially those phenomena that are associated with evident movements, such as locomotion, breathing, nutrition, the heartbeat and others. In fact, it is not difficult to analyze into their primary constituents the complex occupations of our present life, and to recognize that its diversity is produced by various combinations of a few elementary phenomena, such as nutrition, respiration, growth, reproduction, movement and the production of heat."

It must be remembered, however, that such a conception of life is limited to the vital phenomena of human beings, while the field of life is far greater. Animals and plants likewise exhibit vital phenomena, and it may be asked whether these latter are the same as or different from the phenomena that prevail among men. It is evident that all living organisms must be included in the sphere of physiological investigation, the flower and the worm equally with man. Hence the first duty of physiology is to mark out the field of the living, to determine what is living and what is not living—an undertaking that is more difficult than it appears.

The conception of life has not always been the same. It has experienced fundamental changes in the course of the development of the human species. Formed first with respect to mankind, it was early extended to other objects. With primitive races, the conception was much wider than at present, and they termed living what is no longer regarded as such. With them stars, fire, wind and waves were beings endowed with life and mind, and they were personified in the image of man. The remains of these ideas are still found in the mythology of the classic and modern races. In the course of time the distinction between living and lifeless has been made constantly sharper, but even to-day a child regards a steam engine as a living animal. The child is guided more or less consciously by the same criterion as the primitive races, who, from the fact of motion, considered as living the dancing flame of a fire or a moving wave. In fact of all vital phenomena, motion is that which gives most strongly the impression of living.

It may be said that only primitive races and children are misled by the criterion of motion, and that the civilized and adult man, who is versed in a knowledge of life, is capable of deciding easily in any given case between the living and the lifeless. But this is not always true. For example, are dried grains living or lifeless? Is a lentil that has lain unchanged in a chest for years living? Scientific men themselves are not agreed upon this point. The lentil, when dry, does not show phenomena of life, but, if placed in moist earth, it can at any moment be induced to do so. It then sprouts and grows into a plant.

The decision between the living and the lifeless becomes, however, much more difficult with objects that are not commonly seen in daily life—*e.g.*, certain microscopic things. Long observation and very detailed investigation are frequently required in order to determine whether certain bodies that are found in a liquid by microscopic examination are living or not. If a drop of the dregs be taken from a bottle of weissbeer and examined with the microscope, it will be found that the liquid contains innumerable small pale globules, often clinging together in groups of two or three, completely at rest so long as they are observed, and showing no trace of movement or other change. Very similar small globules may be observed with a microscope in a drop of milk. The two kinds of globules can be distinguished from one another by strong magnifying powers only.

No trace of vital phenomena can be found in either by the most patient and continued microscopic examination, yet the two objects are as widely different as a living organism and a lifeless substance; for the globules from the beer are the so-called yeast-cells, the active agent in the fermentation of the beer, and are fully developed, unicellular, living organisms, while the globules from the milk are lifeless droplets of fat, which, by their abundant presence and their reflection of light from all sides, give to the milk its white color. The manifestation of motion, which is often ascribed to an internal source because no external source is directly visible, thus frequently misleads to the assumption of life.

Hence, under certain circumstances it is not at all easy to distinguish the living from the lifeless, and it is accordingly clear that the first duty of physiology must be to inquire after the criteria of such a distinction—*i.e.*, mentally to circumscribe the subject-matter, life, in relation to non-living nature.

The distinction between living and lifeless matter is made still more complicated by the fact that the living substance of the human body, or of any animal or plant, is only the transformed lifeless matter of the food which has been taken into the body and has there assumed, for the time, the living state. Lifeless matter in the shape of food is continually streaming into all living things on the one hand and passing out again as waste on the other. In its journey through the organism some of this matter enters into the living state and lingers for a time as part of the bodily substance. But sooner or later it dies and is then for the most part cast out of the body (tho a part may be retained within it, either as an accumulation of waste material, or to serve some useful purpose). Matter may thus pass from the lifeless into the living state and back again to the lifeless, over and over in never-ending cycles. A living plant or animal is like a whirlpool into which, and out of which, matter is constantly streaming, while the whirlpool maintains its characteristic form and individuality.

"To put the matter in the most general shape," says Huxley, "the body of the organism is a sort of focus to which certain material particles converge, in which they move for a time, and from which they are afterward expelled in new combinations. The parallel between a whirlpool in a stream and a living being, which has often been drawn, is as just as it is striking. The whirlpool is permanent, but the particles of water which constitute it are incessantly changing. Those which enter it on the one side are whirled around and temporarily constitute a part of its individuality; and as they leave it on the other side, their places are made good by newcomers.

"Those who have seen the wonderful whirlpool, three miles below the Falls of Niagara, will not have forgotten the heaped-up wave which tumbles and tosses, a very embodiment of restless energy, where the swift stream hurrying from the Falls is compelled to make a sudden turn toward Lake Ontario. However changeful in the contour of its crest, this wave has been visible, approximately in the same place and with the same general form, for centuries past. Seen from a mile off, it would appear to be a stationary hillock of water. Viewed closely it is a typical expression of the conflicting impulses generated by a swift rush of material particles.

"Now, with all our appliances, we cannot get within a good many miles, so to speak, of the living organism. If we could, we should see that it was nothing but the constant form of a similar turmoil of material molecules, which are constantly flowing into the organism on the one side and streaming out on the other."

What are the distinctive properties of living matter as contrasted with lifeless matter? What are the elementary vital phenomena? The composition of living substance has long been supposed to hold the key to the mysteries of life manifestations. The ancients naïvely believed that they were able to explain the substance of living bodies by the intermixture of certain materials. Thus, Hippocrates believed that the normal human body consists of blood, phlegm and bile, which are mixed together in certain proportions. In the middle ages, when people endeavored to solve the riddle of nature by the great power of alchemy, they thought that they were upon the track of the secret of living substance. How strong this delusion was is shown by the many attempts of the middle ages to produce living substance artificially.

The ardent expectation with which the medieval alchemist in the somber dusk of his laboratory, surrounded by skilled workers and strange apparatus, hoped every moment to see the homunculus arise complete from the retorts or crucibles is a very characteristic feature of the developmental stage of science during these centuries. But. however proud moderns may be of the advancement of science, they have no right to look with scorn upon those attempts of the middle ages, when it is realized that from that time even to the most recent period the attempts have been continued to produce artificially not man himself, but the simplest forms of living substance. Yet all these attempts resemble the endeavor of a man to put together a complicated clock-work without knowing its essential parts.

"However simple the problem of the artificial production of living substance appeared to the middle ages," says Verworn, "the progress of sober thought and critical investigation has shown constantly how far we are yet from a knowledge of the intimate composition of such substance. How is it possible to produce chemically a substance the chemical composition of which is not at all known? Modern research has been directed, therefore, more and more toward an examination of the composition of living substance. It has penetrated deeply, and continues to penetrate, into the morphological, physical and chemical relations, and the intimate structure of living matter."

Altho this accumulated knowledge concerning the composition of living matter does not distinguish between the living and the lifeless, it has given many interesting facts concerning the properties of living matter. In its physical properties living matter in animal and plant tissues behaves like a liquid. The idea that vital phenomena can be associated with a solid substratum only is not only unjustified, but even untenable. Not only is it unsupported on any acceptable ground, but it even contradicts facts that may easily be observed. It is quite impossible to understand how protoplasm in the more or less stiff condition of a framework or network can be capable of streaming and flowing as can be observed so easily in certain plant-cells and in Amoeba. It is impossible for a solid network to flow in such a manner that the individual particles of its mass mix continually with one another, as may be seen so clearly in Amoeba. If at first sight the theory of the solid consistency may not be incompatible with the behavior of cells that possess a constant form, it is absolutely so with the phenomena exhibited by naked protoplasmic masses. Hence various investigators, especially Berthold and Bütschli, have recently defended strongly the idea of the liquid nature of the cell-contents, and no investigator who is familiar with the phenomena need hesitate to accept this view.

Living material has a greater density than water. That some animals and plants float is due to the accumulation in their tissues of certain lifeless matters such as fat and gases, which diminish their specific gravity.

In chemical structure the differences between living and lifeless matter, although not distinctive, are of importance. Only twelve elements are found constantly in living matter: carbon, nitrogen, sulphur, hydrogen, oxygen, phosphorus, chlorine, potassium, sodium, magnesium, calcium and iron. A few others, silicon, fluorine, bromide, iodine, aluminium and manganese are found occasionally. But all these elements are also found in the lifeless matter composing the air, water and the surface of the earth.

Since the chemical analysis of living substance has shown that no constituent but these organic elements are to be found in the organism, the important factor follows that an elementary vital substance exists no more than a specific vital force. The conception of a "vital ether," a "spiritus animalis," a "vital matter," etc., with which the earlier physiology so freely dealt, have, therefore, in harmony with the advanced development which analytical chemistry has undergone at the present time, completely disappeared from the present theory of life; living substance is composed of no different chemical materials from those occurring within lifeless bodies.

Nevertheless, one fact deserves mention, viz., that the few general organic elements are not scattered irregularly here and there through the natural system of elements, but they occupy a definite position, being remarkable as elements having very low atomic weights. "Hence," writes Verworn, "the conclusion may with great probability be drawn that in the evolution of the elements the organic elements arose by condensation very early, and therefore existed in the very early stages of the development of our planetary system, at a time when other elements, such as the heavy metals, had not yet been formed."

Following the discovery that living matter contains no distinctive chemical elements, physiological chemists turned their attention to the search for specific chemical compounds. Here the investigation is most difficult. It is not possible to apply the methods of chemistry to living substance without killing it. Every chemical reagent that comes in contact with it disturbs it and changes it, and what is left for investigation is no longer living substance, but a corpse—a substance that has wholly different properties. Hence ideas upon the chemistry of the living object can be obtained only by deductions from chemical discoveries in the dead object, deductions the correctness of which can be proved experimentally in the living object only in rare cases.

This alone is responsible for the excessively slow advance of the knowledge of the chemistry of the vital process. It is evident that the greatest foresight is necessary in applying results obtained upon the dead object to conditions in the living, and it must constantly be borne in mind that the chemical relations of the latter are to be distinguished sharply from those of the former.

Altho there is no fundamental difference between the elements composing living and those composing lifeless substance, in other words, altho no special vital element exists in the organic world, some of the elements in living substance form unique compounds which characterize it only, and are never found in lifeless substance. Thus there exist in the former, besides chemical compounds that occur also in the latter, specific organic complexes of atoms. Many of these organic compounds, especially those that are of special importance to living substance, possess so complicated a constitution that thus far chemistry has not succeeded in obtaining an insight into the spatial relations of the atoms in their molecules, altho the percentage composition of the molecules is known to a greater extent.

There are especially three chief groups of chemical bodies and their transformation-products, by the presence of which living substance is distinguished from lifeless substance; these are proteids, fats and carbohydrates. Of these only the proteids and their derivatives have been demonstrated with certainty as common to all cells; hence they must be set apart among the organic constituents of living matter as the essential or general substances, in contrast to all special substances.

It is not, however, the mere presence of proteid which is characteristic of living matter. White of egg (albumen) contains an abundance of a typical proteid and yet is absolutely lifeless. Living matter does not simply contain proteids, but has the power to manufacture them out of other substances; and this is a property of living matter exclusively. While the other organic compounds—carbohydrates, fats and some simpler substances—have not been found in all living matter, it is a significant fact that they are derived from proteids and are necessary to the construction of proteids.

But even the presence of the so-called organic compounds—proteids, carbohydrates and fats—is an uncertain distinction between the living and the lifeless, for chemistry is rapidly breaking down the supposed barrier between the organic and the inorganic. Each year records new synthetic combinations of compounds supposed to be produced by living matter. Who knows when even the proteid molecule may yield its secret to some synthetic chemist?

Thus the conclusion is reached, strange at first sight, that the matter constituting the living world is identical with that which forms the inorganic world. "And not less true," says Huxley, "is it that, remarkable as are the powers, or, in other words, as are the forces which are exerted by living beings, yet all these forces are either identical with those which exist in the inorganic world, or they are convertible into them. I mean in just the same sense as the researches of physical philosophers have shown that heat is convertible into electricity, that electricity is convertible into magnetism, magnetism into mechanical force or chemical force, and any one of them into the other, each being measurable in terms of the other—even so, I say that great law is applicable to the living world."

The composition of living matter as known in modern chemistry then does not satisfactorily distinguish between living and lifeless matter, and the question, what is the characteristic difference? again forces itself to the center of attention. The generally accepted answer is that this difference is to be found in certain powers or properties of living matter. These are the power of waste, repair and growth and the power of reproduction. "Living matter," to quote from Sedgwick and Wilson, "is continually wasting away by a kind of internal combustion, but continually repairs the waste by the process of growth. Moreover, this growth is of a characteristic kind, differing absolutely from the so-called growth of lifeless things. Crystals and other lifeless bodies grow, if at all, by accretion, or the addition of new particles to the outside. Living matter grows from within by intussusception, or taking in new particles, and fitting them into the interstices between those already present, throughout the whole mass. And lastly, living matter not only thus repairs its own waste, but also gives rise by reproduction to new masses of living matter which become detached from the parent mass and enter forthwith upon an independent existence.

"We may perceive how extraordinary these properties are by supposing a locomotive engine to possess like powers: to carry on a process of self-repair in order to compensate for wear, to grow and increase in size, detaching from itself at intervals pieces of brass or iron endowed with the power of growing up step by step into other locomotives capable of running themselves, and of reproducing new locomotives in their turn. Precisely these things are done by every living thing, and nothing in any degree comparable with them takes place in the lifeless world."

In connection with the foregoing it should be noted that some modern authors, notably Verworn, hold that even metabolism (the power of waste, repair and growth) does not constitute a fundamental contrast between living organisms and inorganic bodies. For example, there are rare cases known to chemists in which simple chemical compounds under certain conditions undergo a regular succession of destructions and constructions, always with the gain or loss of substances which correspond in principle to the continued streaming of matter through the constructive and destructive changes in the metabolism of living substances. Metabolism, then, cannot be said to be absolutely distinctive, as a general principle, of living matter, but practically the metabolism of proteid which is found in nature only in organic bodies, is sufficiently distinctive of living matter. The discovery of apparently analogous processes in inorganic substances simply suggests that the chemical changes concerned in the powers or activities of living matter are subject to the same fundamental laws as govern change in lifeless matter.

Certain critical physiologists have pointed out that reproduction is not absolutely distinctive. It is true that in higher organisms in which reproduction involves development of eggs, seeds or germs, reproduction is absolutely incomparable with any process in lifeless matter, but many microscopic organisms reproduce by simple division without development, and such simple reproduction is not far removed from similar changes which may occur in lifeless matter. But here again these are really only suggestions of similarity between living and lifeless processes. To most present-day biologists the known facts of reproduction, like those of metabolism, are not in any scientific sense paralleled by processes occurring in inorganic matter.

Finally, even the method of growth by intussusception of particles has been said to offer no criterion of distinction, for liquids (and living matter is liquid) grow by intussusception. However, this strikes many biologists as a mere quibble with words, for growth by intussusception in organisms involves other changes—*e.g.,* foods not proteids may be the material for growth of plant proteid, and plant proteid may in turn serve as food for growth and give rise to animal proteid.

Such critical comparisons suggesting that metabolism, growth and reproduction are not entirely absent from lifeless matter are interesting, but in the present state of scientific knowledge the processes involved in waste, repair, growth and reproduction are to be considered strikingly characteristic of living matter. These are probably complications of simple chemico-physical processes, some of which suggest similarity between living and lifeless matter, but the very complexity of the metabolic and reproductive processes in living forms is distinctive. A parallel case is that of proteid, of which, as has been stated, the most distinctive feature is the complexity of its molecule.

CHAPTER III

PHYSIOLOGICAL IDEA OF LIFE

Accepting the complicated processes of metabolism and reproduction as distinguishing characteristics of life, the force back of these distinctive powers or properties of living matter becomes a fruitful topic for investigation. Thompson in the "Science of Life" discusses this question. "Over and over again in the history of Biology the doctrine of a special vital force has arisen, held sway for a time, and then disappeared. It arises as a reaction from the false simplicity of premature solutions, or as a despairing retreat in the fact of baffling problems, or as the result of misunderstanding the real aim of science.

"The doctrine is an old one, for even if we ignore the speculations of the ancients, it must date at least from Paracelsus and Van Helmont. As it has naturally taken very difficult forms in different generations, the word "vitalism," so often used, has little definite meaning. There is a sense in which no modern physiologist is a vitalist, since none rejects physico-chemical interpretations as the early French vitalists did; there is a sense in which all modern physiologists are vitalists, since none pretends to know the secret of that particular synthesis which even the simplest of organisms illustrates.

"The phrase 'vital force' may be used as a general expression for the energies resident in living matter, and may serve to suggest that we do not at present understand them, or how they are related in the unity of the organism. But the phrase was originally used to denote a 'hypermechanical force,' a mystical power, resident in living creatures, and quite different from thermic, electric, and other forms of energy. This was the meaning attached to the phrase by the disciples of Haller, by Louis Dumas (1765-1813), by Reil (1759-1813), and the other early vitalists. It can only be said that an appeal to such a force violates the scientific method, and abandons the scientific problem. Again and again, in regard to particular points, subsequent progress has shown that the loss of faith in science was premature.

"According to the hypothesis of vitalism the phenomena of life are inexplicable apart from a special vital force exclusively resident in organisms, and different from the chemico-physical energies of the inanimate world. Thus the great pathologist and anatomist Henle (d. 1885) believed in a non-material agent associated with the organism, 'presiding over the metabolism of the body, capable of reproducing the typical form, and of endless partition without diminution of intensity.' It is altogether an error to suppose that a refusal to believe in such a special 'vital force' implies materialism. The questions are quite separate; the former has to do with scientific method, the latter is a philosophical theory. Thus Huxley was certainly no believer in 'a vital force,' yet he was clearly an idealist; and the same might be said of many.

"Every physiologist will, I believe, admit that he cannot at present give a physico-chemical interpretation of contractility or of irritability, of digestion or of absorption, of respiration or of circulation. What he can give is a partial analysis of these functions in simpler terms. This must remain the case until we discover the secret of the synthesis which the simplest unicellular organism expresses. The 'neo-vitalists,' such as Bunge and Rindfleisch, emphasize the fact that there is no present possibility of giving a complete chemico-physical restatement of any observed function; that there are always residual phenomena; and that the known physico-chemical causes do not seem adequate to the result. In other words, the categories of mechanism, of chemistry and physics, cannot be forced upon vitality without doing violence to the very idea of the organism—a complex adaptive synthesis of matter and energy whose secret remains unread. When the neo-vitalists go further, and insist on an idealistic as opposed to a materialistic conception, they may be quite correct, but they are raising another question, which is philosophical rather than biological."

Huxley, in his famous address "On the Physical Basis of Life," has well stated the case against the existence of a vital force. "What justification is there, then," he says, "for the assumption of the existence in the living matter of a something which has no representative, or correlative, in the not living matter which gave rise to it? What better philosophical status has 'vitality' than 'aquosity'? And why should 'vitality' hope for a better fate than the other 'itys' which have disappeared since Martinus Scriblerus accounted for the operation of the meat-jack by its inherent 'meat-roasting quality,' and scorned the 'materialism' of those who explained the turning of the spit by a certain mechanism worked by the draft of the chimney?

"If scientific language is to possess a definite and constant signification whenever it is employed, it seems to me that we are logically bound to apply to the protoplasm, or physical basis of life, the same conceptions as those which are held to be legitimate elsewhere. If the phenomena exhibited by water are its properties, so are those presented by protoplasm, living or dead, its properties. If the properties of water may be properly said to result from the nature and disposition of its component molecules, I can find no intelligible ground for refusing to say that the properties of protoplasm result from the nature and disposition of its molecules."

This idea of the physical basis of life, so clearly stated by Huxley, has been further developed by Dr. Michael Foster, whose line of thought is as follows: "The more the molecular problems of physiology are studied, the stronger becomes the conviction that the consideration of what we call structure and composition must, in harmony with the modern teachings of physics, be approached under the dominant conception of modes of motion. The physicists have been led to consider the qualities of things as expressions of internal movements; even more imperative does it seem to us that the biologist should regard the qualities of living matter (including structure and composition) as in like manner the expressions of internal movements. He may speak of living matter as a complex substance, but he must strive to realize that what he means by that is a complex whirl, an intricate dance, of which what he calls chemical composition, histological structure and gross configuration are, so to speak, the figures; to him the renewal of protoplasm is but the continuance of the dance, its functions and actions the transferences of the figures. It seems to us necessary, for a satisfactory study of the problems, to keep clearly before the mind the conception that the phenomena in question are the result, not of properties of kinds of matter, but of kinds of motions."

Before passing from the consideration of vital force and the physical basis of life, it will be of interest to compare the views of the biologists Huxley and Foster with that expressed in a lecture by the great physicist, Tyndall.

"The origin, growth and energies of living things," he reminded his hearers, "are subjects which have always engaged the attention of thinking men. To account for them it was usual to assume a special agent, free to a great extent from the limitations observed among the powers of inorganic nature. This agent was called vital force; and, under its influence, plants and animals were supposed to collect their materials and to assume determinate forms. Within the last few years, however, our ideas of vital processes have undergone profound modifications; and the interest, and even disquietude, which the change has excited are amply evidenced by the discussions and protests which are now common, regarding the phenomena of vitality. In tracing these phenomena through all their modifications, the most advanced philosophers of the present day declare that they ultimately arrive at a single source of power, from which all vital energy is derived; and the disquieting circumstance is that this source is not the direct fiat of a supernatural agent, but a reservoir of what, if we do not accept the creed of Zoroaster, must be regarded as inorganic force. In short, it is considered as proved that all the energy which we derive from plants and animals is drawn from the sun.

"A few years ago, when the sun was affirmed to be the source of life, nine out of ten of those who are alarmed by the form which this assertion has latterly assumed would have assented, in a general way, to its correctness. Their assent, however, was more poetic than scientific, and they were by no means prepared to see a rigid mechanical signification attached to their words. This, however, is the peculiarity of modern conclusions: that there is no creative energy whatever in the vegetable or animal organism, but that all the power which we obtain from the muscles of man and animals, as much as that which we develop by the combustion of wood or coal, has been produced at the sun's expense.

"To most minds, however, the energy of light and heat presents itself as a thing totally distinct from ordinary mechanical energy. Either of them can nevertheless be derived from the other. Wood can be raised by friction to the temperature of ignition; while by properly striking a piece of iron a skilful blacksmith can cause it to glow. Thus, by the rude agency of his hammer, he generates light and heat. This action, if carried far enough, would produce the light and heat of the sun. In fact, the sun's light and heat have actually been referred to the fall of meteoric matter upon his surface; and whether the sun is thus supported or not, it is perfectly certain that he might be thus supported. If, then, solar light and heat can be produced by the impact of dead matter, and if from the light and heat thus produced we can derive the energies which we have been accustomed to call vital, it indubitably follows that vital energy may have a proximately mechanical origin.

"In what sense, then, is the sun to be regarded as the origin of the energy derivable from plants and animals? Let us try to give an intelligible answer to this question. Water may be raised from the sea-level to a high elevation, and then permitted to descend. In descending it may be made to assume various forms—to fall in cascades, to spurt in fountains, to boil in eddies, or to flow tranquilly along a uniform bed. It may, moreover, be caused to set complex machinery in motion, to turn millstones, throw shuttles, work saws and hammers, and drive piles. But every form of power here indicated would be derived from the original power expended in raising the water to the height from which it fell. There is no energy generated by the machinery: the work performed by the water in descending is merely the parceling out and distribution of the work expended in raising it.

"In precisely this sense is all the energy of plants and animals the parceling out and distribution of a power originally exerted by the sun. In the case of the water, the source of the power consists in the forcible separation of the quantity of the liquid from a low level of the earth's surface, and its elevation to a higher position, the power thus expended being returned by the water in its descent. In the case of vital phenomena, the source of power consists in the forcible separation of the atoms of compound substances by the sun. We name the force which draws the water earthward 'gravity,' and that which draws atoms together 'chemical affinity'; but these different names must not mislead us regarding the qualitative identity of the two forces. They are both attractions; and, to the intellect, the falling of carbon atoms against oxygen atoms is not more difficult of conception than the falling of water to the earth.

"The building up of the vegetable, then, is effected by the sun, through the reduction of chemical compounds. The phenomena of animal life are more or less complicated reversals of these processes of reduction. We eat the vegetable, and we breathe the oxygen of the air; and in our bodies the oxygen, which had been lifted from the carbon and hydrogen by the action of the sun, again falls toward them, producing animal heat and developing animal forms. Through the most complicated phenomena of vitality this law runs: the vegetable is produced while a weight rises, the animal is produced while a weight falls.

"But the question is not exhausted here. The water employed in our first illustration generates all the motion displayed in its descent, but the form of the motion depends on the character of the machinery interposed in the path of the water. In a similar way, the primary action of the sun's rays is qualified by the atoms and molecules among which their energy is distributed. Molecular forces determine the form which the solar energy will assume. In the separation of the carbon and oxygen this energy may be so conditioned as to result in one case in the formation of a cabbage, and in another case in the formation of an oak. So also, as regards the reunion of the carbon and the oxygen, the molecular machinery through which the combining energy acts may, in one case, weave the texture of a frog, while in another it may weave the texture of a man.

"The matter of the animal body is that of inorganic nature. There is no substance in the animal tissues which is not primarily derived from the rocks, the water and the air. Are the forces of organic matter, then, different in kind from those of inorganic matter? The philosophy of the present day negatives the question. It is the compounding, in the organic world, of forces belonging equally to the inorganic, that constitutes the mystery and the miracle of vitality. Every portion of every animal body may be reduced to purely inorganic matter. A perfect reversal of this process of reduction would carry us from the inorganic to the organic; and such a reversal is at least conceivable. The tendency, indeed, of modern science is to break down the wall of partition between organic and inorganic, and to reduce both to the operation of forces which are the same in kind, but which are differently compounded.

"Consider the question of personal identity, in relation to that of molecular form. Thirty-four years ago, Mayer of Heilbronn, with that power of genius which breathes large meanings into scanty facts, pointed out that the blood was "the oil of the lamp of life," the combustion of which sustains muscular action. The muscles are the machinery by which the dynamic power of the blood is brought into play. Thus the blood is consumed. But the whole body, tho more slowly than the blood, wastes also, so that after a certain number of years it is entirely renewed. How is the sense of personal identity maintained across this flight of molecules? To man, as we know him, matter is necessary to consciousness; but the matter of any period may be all changed, while consciousness exhibits no solution of continuity. Like changing sentinels, the oxygen, hydrogen and carbon that depart seem to whisper their secret to their comrades that arrive, and thus, while the Non-ego shifts, the Ego remains the same. Constancy of form in the grouping of the molecules, and not constancy of the molecules themselves, is the correlative of this constancy of perception. Life is a wave which in no two consecutive moments of its existence is composed of the same particles.

"Supposing, then, the molecules of the human body, instead of replacing others, and thus renewing a preëxisting form, to be gathered first hand from nature and put together in the same relative positions as those which they occupy in the body. Supposing them to have the selfsame forces and distribution of forces, the selfsame motions and distribution of motions—would this organized concourse of molecules stand before us as a sentient thinking being? There seems no valid reason to believe that it would not. Or, supposing a planet carved from the sun, set spinning round an axis, and revolving round the sun at a distance from him equal to that of our earth, would one of the consequences of its refrigeration be the development of organic forms? I lean to the affirmative. Structural forces are certainly in the mass, whether or not those forces reach to the extent of forming a plant or an animal. In an amorphous drop of water lie latent all the marvels of crystalline force; and who will set limits to the possible play of molecules in a cooling planet? If these statements startle, it is because matter has been defined and maligned by philosophers and theologians, who were equally unaware that it is, at bottom, essentially mystical and transcendental."

Summarizing the foregoing discussion concerning the nature and general conditions of life and living matter, the fact stands out clearly and distinctly that life from its beginning has been dependent upon the external conditions of the earth's surface. In a mathematical sense, life is a function of the earth's development. Living substance could not exist while the earth was a molten sphere without a solid crust; it was obliged to appear with the same inevitable necessity as a chemical combination, when the necessary conditions were given, and it was obliged to change its form and its composition in the same measure as the external conditions of life changed in the course of the earth's development. It is only a portion of the earth's matter.

The combination of this matter into living substance was as much the necessary product of the earth's development as was the origin of water. It was an inevitable result of the progressive cooling of the masses that formed the earth's crust. Likewise, the chemical, physical and morphological characteristics of existing living substance are the necessary result of the influence of the external conditions of life upon the internal relations of past living substance. Internal and external vital conditions are inseparably correlated and the expression of this correlation is life.

The artificial production of life would thus seem a theoretical possibility. It has been several times suggested in the discussion of the chemical aspects of life that living matter may sooner or later be produced in the chemists' laboratories. However improbable this suggestion may seem, there are many facts which point to its possibility. Heraclitus compared life with fire. Such a comparison is a pertinent one. Consideration of vital conditions makes this more evident. "It has been shown that life," to quote Verworn, "like fire, is a phenomenon of nature which appears as soon as the complex of its conditions is fulfilled.

"If these conditions are all realized, life must appear with the same necessity as fire appears when its conditions are realized; likewise life must cease as soon as the complex of its conditions has undergone disturbance and with the same necessity with which fire is extinguished when the conditions for its maintenance cease. If, therefore, all vital conditions had been investigated in their minutest details, and it were possible artificially to establish them exactly, life would be produced synthetically, just as fire is produced, and the ideal that existed in the imagination of the medieval alchemists in their attempted production of the hōmunculus would be achieved."

But, notwithstanding the fact that this theoretical possibility cannot be denied, every attempt at the present time to produce life artificially and to imitate in the laboratory the obscure act of spontaneous generation must appear preposterous. So long as knowledge of the composition of living substance is so imperfect as it is now, the attempt artificially to compound living substance will be like the undertaking of an engineer to put together a machine, the most important parts of which are wanting. For the present the task of physiology can consist only in the investigation of life. When physiology shall actually have accomplished this, it may think of testing the completeness and correctness of its achievement by the artificial creation of life.

The nature of life has become better understood by the study of death, which to the biologist is simply the cessation of the activities of life. In the first place it is sometimes extremely difficult to distinguish between life and apparent death. Several illustrations will make this clear. In India, where mystery and magic have always prevailed, the belief seems to have existed for a long time that many men, especially the so-called fakirs whose existences are full of privation and self-inflicted torture and who are supposed to possess special holiness, have the remarkable power of voluntarily putting a complete stop to their lives for a time and later resuming them undisturbed and unchanged. A great number of such cases, in which the fakirs have been buried in this condition of suspended animation and after some time have been taken from their graves, have been reported by travelers from India.

It is not to be denied that these tales, especially those of the Indian fakirs, are calculated to awaken distrust, and a sound skepticism is the basis of all good criticism. If, however, from all the known stories their more or less sensational accompaniments be removed, the simple statement remains that certain men can voluntarily put themselves into a state in which no vital phenomena are demonstrable by a more or less superficial examination and can awaken later to normal life. Now sufficient cases are known where physicians by the usual methods of their practice are able to discover absolutely no traces of vital phenomena, where pulse, respiration, movement and irritability are not to be observed; and yet where the person, supposedly dead, has after a time returned to life.

These phenomena are usually termed "apparent death" and are connected with those of normal sleep by a series of transition phenomena. Such transition phenomena are the continual sleep in which persons, such as the "sleeping soldier" and the "sleeping miner" (authenticated medical cases), continue in a state of depressed vital activity and are absolutely incapable of being awakened, and especially the phenomena of the winter sleep of warm-blooded animals.

However doubtful may be the reported powers of representatives of the vertebrate (or backboned) animals to suspend for a time all vital phenomena, there is no longer any question that many of the lower animals have this power highly developed. As long ago as 1719 Leeuwenhock, the famous improver of the microscope, discovered that small animals, now known as rotifers, may be dried completely to dust and again restored to active life by being placed in water. One of the most remarkable cases of this kind described by Verworn is that of the tardigrade, or bear-animalcule, which, so long as it is in water, performs all its vital phenomena like other animals. "But if it be isolated and allowed to dry slowly upon a slide, it is seen that the more the water evaporates the slower becomes its movements, until finally they cease entirely when the drop is dried up. Then the body gradually shrinks, the skin becomes wrinkled and folded, the form becomes gradually indistinguishable, and some time after the animal has become dried it can scarcely be distinguished from a grain of sand. In this dried condition it can remain for many years without undergoing the slightest change. If it be moistened again with water, the return of life to the desiccated body after its sleep can be followed with the microscope. The awakening of the tardigrade or the anabiosis, as Preyer has termed the process, takes place somewhat as follows: The body swells up and becomes extended, the folds and wrinkles slowly disappear, the extremities project and the animal soon assumes its normal shape." At first it remains quiet; then, after a time, varying, according to the duration of the drying, from a quarter of an hour to several hours, movements, at first slow and feeble, begin and gradually become stronger and more frequent until after some time the animal, unaided, creeps away to resume life at the point where it was interrupted.

Likewise the seeds of many plants retain their power of germination for long periods of time. Here it might be well to add that the well-known story that wheat seeds taken from the graves of Egyptian mummies will germinate, tho thousands of years old, has been disproved by Mariette, the famous Egyptologist. However, from many observations it seems certain that many plant seeds, when completely dried, can retain their power to germinate for more than a hundred or perhaps two hundred years. These rare facts are of great importance in forming a conception of life and demand exhaustive investigation. The question to be considered is whether it is allowable to regard organisms in this peculiar condition as really lifeless.

It has been pointed out in the earlier part of this chapter that it is metabolism in which the living organism differs from lifeless matter. But this is difficult to settle in some of the concrete cases mentioned above. Do dust-dry animals and seeds possess no metabolism or is this metabolism so depressed or so slight that investigation cannot determine whether the life-process is at a standstill or whether a "vita minima" exists? Delicate experiments within the last twenty years show no evidence of the use of oxygen or the production of carbonic acid or other products of metabolism in dried organisms sealed for months in air-tight tubes.

From the results of these experiments it can no longer be doubted that in desiccated organisms there is a complete standstill of life. Can organisms in this peculiar condition be termed dead? In reality they are lifeless but not dead, for anabiosis is possible after the application of water, while nothing can bring dead organisms back to life. The distinction between the dried and the dead organism lies in the fact that in the former all the internal vital conditions are still fulfilled and only the external conditions in part have appeared, while in the latter the internal vital conditions have experienced irreparable disturbances, altho the external conditions can still be fulfilled.

Preyer illustrates this distinction very happily. He compares the dried organism to a clock that has been wound but has stopped, so that it needs only a push to set it going, and the dead organism to a clock that is broken and cannot be made to go by a push. Hence a sharp distinction must be made between dried and dead organisms. But dried organisms cannot be called living, for they exhibit no vital phenomena, and, as has been seen, vital phenomena are the criterion of life. It is best, therefore, to apply to them the expression "apparently dead."

Still more difficult than cases of apparent death is the determination of an exact limit between life and active death. In daily life it is easy to distinguish the dead organism from the living, for from the human body and from the higher animals a general conception of death has been formed and it is usual to consider it as occurring at the moment when the heart, hitherto never quiet, stands still and the individual ceases to breathe. But this is merely following the superficial habits of daily life and taking into consideration only the gross differences that make their appearance at that time, without noticing the continuance of certain phenomena after this all-important moment.

The criterion of life is formed only by the vital phenomena—*i.e.*, by the various phases in which the vital process, or the metabolism, becomes evident to the senses. But if this criterion be applied to the human being at the moment usually termed the moment of death, it is found that in reality he is not dead.

It is true that the spontaneous gross muscular movements cease, the man becomes relaxed and quiet. But the muscles frequently remain for several hours sensitive to external influences, responding to the latter with twitchings and movements of the limbs, in other words, showing vital phenomena. A moment even comes when the muscles gradually contract once more spontaneously, this is the death-stiffening (rigor mortis). Not until this has passed is the life of the muscles extinguished. Nevertheless, even then the body is not entirely dead. Certain parts only, certain organs or cell-complexes, such as the cells of the nervous system and of the muscles, no longer show vital phenomena; but other cells and cell-complexes continue to live unchanged long after rigor mortis has passed.

What moment then shall be designated as the moment of death? If the existence of vital phenomena be employed as the criterion, then the moment when spontaneous muscular movement, especially the activity of the heart, ceases, cannot consistently be regarded as the moment of death, for other cell-complexes continue to live for a long time thereafter. It is evident, therefore, that there is no definite point of time at which life ceases and death begins; but there is a gradual passage from normal life to complete death which frequently begins to be noticeable during the course of a disease. Death is developed out of life.

It is true that the above example is that of a highly complicated organism. But even in the lowest and simplest microscopic organisms death comes on gradually, and, as in the higher animals, is the end-result of a long series of processes which begin with an irreparable injury to the normal body and lead, step by step, to complete cessation of life activities. To this series of stages in the development of death Schultze and Virchow (1870), famous in pathology, have given the term "necrobiosis," the gradual transition between life and death.

It is seen, therefore, that it is impossible to draw a sharp line between life and death, that life and death are only the two end-results of a long series of changes which run their course successively in the organism. "But if, after having established this fact," says Verworn, "the transition stages be left out of consideration for the moment and only the two end-results be considered, on the one side, the uninjured living organism and, on the other, the same organism killed and preserved in alcohol by the modern technical methods, a sharp distinction between these two can be recognized in the fact that in the former the life-process goes on undisturbed, as is evident from the appearance of all vital phenomena, while in the latter it is forever at a complete standstill, as is shown by the absence of even the slightest phenomena of life."

CHAPTER IV

THE ORIGIN OF LIFE

THE discussion of the origin of life is introduced by J. Arthur Thomson, of Aberdeen University, in "The Science of Life" with the following words: "If it were the object of this book to give a statement of the established facts of biology, our discussion of the origin of life might be condensed into a single sentence: We do not know anything in regard to the origin of life. The only certainty is a negative one—there is no established case in which living organisms have arisen apart from parent organisms of the same kind."

There are two distinct questions connected with the origin of life: First, how did it first originate in the early eras of the world's history? and, second, does life to-day originate spontaneously in inorganic matter? It seems best to consider these separately. Professor Max Verworn, of the University of Jena, gives a good summary of the various theories concerning the origin of life, and it is from his "General Physiology" that some of the following illustrations have been taken.

The origin of life upon the earth is a first and leading problem. The idea that the earth was once in a highly heated condition is accepted in modern science. And this fact that it once was in a condition in which the temperature was enormously high and not a drop of water existed upon it, in short, a condition in which the vital conditions that are now regarded as indispensable to the existence of organisms were wanting, will always be an important factor with which all speculations upon the origin of life upon the earth must deal. Obviously in that highly heated condition life in its present form, at least, could not have existed. Then one of two things must have happened after the earth cooled down—either inorganic matter must have become living matter, or living matter must have come from other planets than this.

But if life came hither from other worlds, the interesting question as to the beginning of life remains. Helmholtz has said, "Organic life either has begun to exist at some one time or has existed for eternity." Evidently the two notions are mutually exclusive. Which affords the most reasonable basis of explanation? The idea that life has existed in the universe from eternity, and has simply been transferred from one world to another, is known as the theory of "cosmozoa." It was suggested by H. E. Richter (1865, '70 and '71), who assumed that among particles moving about in space, like meteorites, there are the germs of microscopic organisms capable of establishing life on the earth. Helmholtz and Sir William Thomson have discussed this question of the transference of living matter from other heavenly bodies to this earth, and both term this view not unscientific. Helmholtz (1884) held that meteors which swarm everywhere in space might be the bearers of such germs in their interior cavities. He thought it a correct scientific procedure to question whether life may not be even as old as matter and its germs passed from world to world and developed wherever favorable conditions exist.

In the present condition of knowledge it is scarcely possible to obtain a direct contradiction of this doctrine and conclusive proof of its impossibility. This will be true so long as experience does not suffice to enable man to recognize as wholly impossible the transfer of protoplasmic germs of life from one world to another. But, altho direct contradiction of the doctrine is at present impossible, the thought that living substance has existed from eternity and has never originated from inorganic substance appears in the highest degree improbable.

Setting aside the "cosmozoa" theory as improbable, and before considering the alternative view of the spontaneous generation of life from lifeless matter on the earth, mention should be made of Preyer's view that living matter is the primary thing and that lifeless matter has been derived from the living. According to this view, life must have existed when the earth was incandescent. Preyer fits his theory to this fact by giving to his conception of life a scope wider than that usually allowed, including not only present living matter but also incandescent liquid masses as they once existed. Life then had no origin; it existed even in the beginning of the material universe. In fact, the view seems to identify life with motion. Evidently the language used constitutes the chief difference between this and the doctrine that living matter as now recognized was spontaneously generated from matter customarily termed lifeless. Whether from primeval conditions incandescent matter, which from our usual standpoint would certainly be considered lifeless, was really living and separated out that which we call lifeless or whether it was lifeless with the power to evolve into living matter are questions of greater metaphysical flavor than of direct interest in the biological science of to-day. In either case the original incandescent matter must have possessed the potentiality of evolving and differentiating into what is now recognized as living and lifeless matter. It matters little whether in philosophical moods it is sought to establish the primary vital force, for after all, as has been shown, vital force is not unique among the forces of the universe.

One of the most suggestive works discussing origin of life from lifeless matter on the earth is by the famous German physiologist Pflüger (1875). He discussed the problem from the standpoint of physiological chemistry and follows it out far into detail. The essential point of Pflüger's investigation is constituted by the chemical characteristics of proteid as that substance with which life in its essentials is inseparably united. There exists a fundamental difference between dead proteid, as it occurs—*e.g.,* in egg-albumen, and living proteid, as it constitutes living substance; this difference is the self-decomposition of the latter. All living substance is continually being decomposed, in some degree spontaneously and more through outside influences, while dead proteid under favorable conditions remains intact for an unlimited time.

Further, Pflüger assumes on scientific grounds that the presence of cyanogen in living matter is responsible for the characteristic properties of living proteid, especially its great powers of decomposition. From this he concludes that the beginning of organic life was in cyanogen. Hence the problem of the origin of living substance culminates in the question: How does cyanogen arise? Here, organic chemistry presents the highly significant fact, that cyanogen and its compounds, such as potassium cyanide, ammonium cyanide, hydrocyanic acid, cyanic acid, etc., arise only in an incandescent heat—*e.g.,* when the necessary nitrogenous compounds are brought in contact with burning coal, or when the mass is heated to a white heat. "Accordingly, nothing is clearer than the possibility of the formation of cyanogen-compounds when the earth was wholly or partially in a fiery or heated state." Moreover, chemistry shows how the other essential constituents of proteid, such as the hydrocarbons, the alcohol radicals, can likewise arise synthetically in heat.

"It is seen," says Pflüger, "how strongly and remarkably all facts of chemistry point to fire as the force that has produced by synthesis the constituents of proteid. In other words, life is derived from fire, and its fundamental conditions were laid down at a time when the earth was still an incandescent ball. If now we consider the immeasurably long time during which the cooling of the earth's surface dragged itself slowly along, cyanogen and the compounds that contain cyanogen and hydrocarbon substances had time and opportunity to indulge extensively their great tendency toward transformation and polymerization and to pass over with the aid of oxygen, and later of water and salts, into that self-destructive proteid, living matter."

Pflüger thereupon summarizes his ideas in the following sentences: "Accordingly, I would say that the first proteid to arise was living matter, endowed in all its radicals with the property of vigorously attracting similar constituents, adding them chemically to its molecule, and thus growing ad infinitum. According to this idea, living proteid does not need to have a constant molecular weight; it is a huge molecule undergoing constant, never-ending formation and constant decomposition, and probably behaves toward the usual chemical molecules as the sun behaves toward small meteors.

"In the plant, living proteid simply continues to do what it has always done since its origin—*i.e.*, regenerate or grow; wherefore I believe that all proteid existing in the world to-day was derived directly from the first proteid."

This idea of Pflüger's in essentials is generally accepted, for most present-day biologists prefer to think of life as having originated directly from substances usually regarded as lifeless and of all existing living proteid as having descended in direct continuity from the first proteid. Moreover, some biologists follow Helmholtz and others in thinking that the first proteid may possibly have originated in some other part of the universe, but astronomy and geology offer good reason for believing that living matter might have originated on the earth when in its evolution to its present state conditions became right for its development.

However, notwithstanding all the speculations concerning the subject, it must be recognized that the problem is one of metaphysics rather than of natural science. The ordinary methods of scientific investigation are not applicable to the problem and one can only theorize as to the basis of life as it is known. But there cannot be any certainty that life in its beginning, under possibly vastly different conditions from those obtaining to-day, possessed the distinctive properties discovered in it by modern science.

That master of modern philosophical biology, Thomas H. Huxley, discussed the origin of life in his Presidential Address before the British Association for the Advancement of Science, forty years ago, and his words, while expressing the ideas outlined above, stand high among the statements of the philosophical problems of biology. "Looking back through the prodigious vista of the past," he writes, "I find no record of commencement of life, and therefore I am devoid of any means of forming a definite conclusion as to the condition of its appearance. Belief, in the scientific sense of the world, is a serious matter and needs strong foundations. To say, therefore, in the admitted absence of evidence, that I have any belief as to the mode in which the existing forms of life have originated, would be using words in a wrong sense.

"But expectation is permissible where belief is not; and if it were given to me to look beyond the abyss of geologically recorded time to the still more remote period when the earth was passing through physical and chemical conditions which it can no more see again than a man can recall his infancy, I should expect to be a witness of the evolution of living substance from non-living matter. I should expect to see it appear under forms of great simplicity, endowed, like existing fungi, with the power of determining the formation of new living matter from such matters as ammonium carbonates, oxalates and tartrates, alkaline and earthy phosphates, and water, without the aid of light. That is the expectation to which analogical reasoning leads me; but I beg you once more to recollect that I have no right to call my opinion anything but an act of philosophical faith."

Since these words were penned the whole development of modern Biology has been insufficient to enable the scientist to do more than repeat Huxley's "philosophical faith." Professor Jacques Loeb, the chief exponent of the mechanistic origin, is careful not to overstate his position. The precise method of the Origin of Life has not been determined in the laboratory. Indeed, suppose that a chemist should manufacture life in his laboratory, many successful repetitive results would be necessary before science could accept it as an established law.

The second question is that of spontaneous generation. Among biologists of the twentieth century, the term has a conservative meaning. It now implies mainly the theory that simple living matter came into existence from natural causes in the early ages of the world's history.

This idea that living things, including even animals as complicated as flies and frogs, originate directly from lifeless matter, long after the first origin of life, has been widely accepted and is believed even to-day by many unscientific people. It is to this supposed origin of living matter within the period of human history that the term "spontaneous generation" is most commonly applied. The fundamental problems would be the same, no matter whether the spontaneous appearance of life in lifeless matter occurred in the beginning of all life or occurs to-day. But the first is entirely beyond the power of scientific investigation, while if life now originates spontaneously a critical application of the methods of modern science ought to prove it and to throw light on the method of origin.

A vast amount of critical work has been done with the result that the biologists of the Victorian era proved that life does not originate spontaneously in any of the cases claimed to have been observed. In other words, life does not now spontaneously originate in lifeless matter so far as is known. This does not mean that it cannot or does not originate in some unknown form. This is a possibility which biologists recognize, and so they stand in an open-minded attitude ready to witness the origin of life from lifeless matter and really somewhat disappointed in that this opportunity has not yet come.

The story of the theory of spontaneous generation is one of the most fantastic in all biology. Thomson says: "If the longevity of a belief were an index to its truth, the theory of spontaneous generation should rank high among the veracities, for it flourished throughout twenty centuries and more. We cannot trace the history of the theory in all its details, but the story may be recommended to the psychological historian as a labyrinth of error, with glimpses of truth at every turn."

The belief in spontaneous generation is recorded in literature back as far as Anaximander (611-547 B.C.). He believed that eels and other aquatic forms are produced directly from lifeless matter. His pupil Anaximenes (588-524 B.C.) "introduced the idea of primordial terrestrial slime, a mixture of earth and water, from which, under the influence of the sun's heat, plants, animals and human beings are directly produced—in the abiogenetic fashion," says Osborn in "From the Greeks to Darwin." Diogenes and Xenophanes, the first to recognize the true nature of fossils, also believed in spontaneous generation. Then came the "father of natural history," Aristotle (384-322 B.C.), who fostered this idea so strongly that it has persisted for more than twenty centuries. He taught that not only small animals, but even frogs, snakes and eels are produced spontaneously from mud.

Long after Aristotle, men found no difficulty in believing in cases of spontaneous generation which would now be rejected as monstrous by the most fanatical supporter of the doctrine. Shell-fish of all kinds were considered to be without parental origin. Eels were supposed to spring spontaneously from the fat ooze of the Nile. Caterpillars were the spontaneous products of the leaves on which they fed; while winged insects, serpents, rats and mice were all thought capable of being generated without sexual intervention.

The development of embryology and the knowledge of the life-histories of plants and animals gradually set aside many supposed cases of spontaneous generation. A little observation showed that individuals of these species developed from eggs produced by parents of the same species. But it is interesting to note that certain philosophers, notably among them being Augustine (353-430), still held to spontaneous generation as occasionally happening in animals reproducing by the sexual method. According to Augustine, from the beginning there had existed two kinds of germs of living things: first, visible ones, placed by the Creator in animals and plants; and second, invisible ones, latent and becoming active only under certain conditions of combination and temperature. It is these which produce plants and animals in great numbers without any coöperation of existing organisms. This was a naturalistic way of explaining the sudden appearance of countless numbers of frogs, insects and other animals which to-day offers no difficulty, now that the remarkable fertility of animals is known.

Even a man like Cesalpino (1519-1603), who did some excellent botanical work, and had, long before Harvey, some clear ideas as to the circulation of the blood, "believed that frogs might be generated from the mud with the help of sunshine," says Thompson, "and even suggested a similar origin of the aboriginal Americans. The botanists were no better than the zoologists. One of their favorite notions was that the green dust which grows in damp weather on trees and stones, which is now known to consist of unicellular Algae, such as 'Pleurococcus,' was a standing evidence of the genetic connection between the dead and the living, between the mineral and the vegetable; even Bacon of Verulam believed in the spontaneous origin of some higher plants, like thistles, from earth; and the Italian botanist Matthioli regarded the duckweed, whose leaf-like shoots are so common on the surface of pools, as a condensation of the still water, and a starting-point for higher forms of plant life; while even Harvey continued to believe in spontaneous generation."

A scientific experiment to test spontaneous generation was first undertaken by Francesco Redi, a distinguished Italian physician and scholar. The origin of maggots from putrefying flesh had long been accepted as a clear case of spontaneous generation. Tyndall, in an article on spontaneous generation, writes of this as follows: "Lacking the checks imposed by fuller investigation, the conclusion that flesh possesses and exerts this generative power is a natural one. I well remember when a child of ten or twelve seeing a joint of imperfectly salted beef cut into, and coils of maggots laid bare within the mass. Without a moment's hesitation I jumped to the conclusion that these maggots had been spontaneously generated in the meat. I had no knowledge which could qualify or oppose this conclusion, and for the time it was irresistible. The childhood of the individual typifies that of the race, and the belief here enunciated was that of the world for nearly two thousand years."

To the examination of this very point the celebrated Francesco Redi addressed himself in 1668. He had seen the maggots of putrefying flesh, and reflected on their possible origin. But he was not content with mere reflection, nor with the theoretic guesswork which his predecessors had founded upon their imperfect observations. Watching meat during its passage from freshness to decay, prior to the appearance of maggots he invariably observed flies buzzing around the meat and frequently alighting on it. The maggots, he thought, might be the half-developed progeny of these flies.

"The inductive guess precedes experiment, by which, however, it must be finally tested. Redi knew this, and acted accordingly. Placing fresh meat in a jar and covering the mouth with paper, he found that, tho the meat putrefied in the ordinary way, it never bred maggots, while the same meat placed in open jars soon swarmed with these organisms. For the paper cover he then substituted fine gauze, through which the odor of the meat could rise. Over it the flies buzzed, and on it they laid their eggs, but the meshes being too small to permit the eggs to fall through, no maggots were generated in the meat. They were, on the contrary, hatched upon the gauze. By a series of such experiments Redi destroyed the belief in the spontaneous generation of maggots in meat, and with it doubtless many related beliefs. The combat was continued by Vallisneri, Schwammerdam and Réaumur, who succeeded in banishing the notion of spontaneous generation from the scientific minds of their day. Indeed, as regards such complex organisms as those which formed the subject of their researches, the notion was banished forever, so far as accepted science was concerned." However, to this day many untutored persons firmly believe that dead horse-hairs placed in water transform themselves into horse-hair eels and that meat generates maggots and other forms of life.

In the latter half of the seventeenth century the great improvement of the microscope as an instrument of investigation paved the way to a new phase of the discussion of spontaneous generation. This came about because of the fact that the instrument brought into view a world of life formed of individuals so minute—so close as it seemed to the ultimate particles of matter—as to suggest an easy passage from atoms to organisms. Animal and vegetable infusions exposed to the air were found clouded and crowded with creatures far beyond the reach of unaided vision, but perfectly visible to an eye strengthened by the microscope. With reference to their origin these organisms were called "Infusoria." Stagnant pools were found full of them, and the obvious difficulty of assigning a germinal origin to existences so minute furnished the precise condition necessary to give new play to the notion of heterogenesis or spontaneous generation.

Many scientific men of that day took up the question of the origin of the microscopic organisms. A Scotch priest, Turbevill Needham (1750), showed that animalcules (Infusorian and the like) appeared even in decoctions which had been boiled and corked up. As we should now say, this result was due to imperfect sterilization and imperfect corking of the tubes; but it was used by Buffon, who was much interested in Needham's work, to bolster up a pet theory of his, that life resided in indestructible organic molecules, and that these were liberated after death or in decomposition as the aforesaid Infusorians or animalcules.

This result of Needham's was contradicted in 1777 by the Abbé Spallanzani who charged his flasks with organic infusions, sealed their necks with the blowpipe, subjected them in this condition to the heat of boiling water, and subsequently exposed them to temperatures favorable to the development of life. The infusions continued unchanged for months, and when the flasks were subsequently opened no trace of life was found. Spallanzani's flasks must have contained but little air and it was objected by chemists, who had now discovered oxygen, that life could not be expected where this gas was more or less absent, and that the boiling process might irretrievably injure the "organic molecules."

Schultze and Schwann (1836, 1837) were thus led to make fresh experiments; they carefully boiled the infusions and supplied air which had been passed through red-hot tubes or acids—, no animalcules appeared; they then supplied air which had not been so purified, and in the same infusions the animalcules appeared. Schwann's final conclusion was "that putrefaction is due to decompositions of organic matter attendant on the multiplication therein of minute organisms. These organisms are derived not from the air but from something contained in the air, which is destroyed by a sufficiently high temperature."

The next step in advance came in 1854, when Schroeder and Dusch did what is now so often done as a class experiment: they boiled infusions, and while the steam was coming off plugged the neck of the flask with cotton-wool. This allows the passage of oxygen, but keeps back germs; and in most cases the sterilization is quite effective. In 1859 a book was published which seemed to overturn some of the best established facts of previous investigators. Its title was "Héterogénie," and its author was F. A. Pouchet, Director of the Museum of Natural History at Rouen, a strong believer in the theory of spontaneous generation. "Never," says Tyndall, "did a subject require the exercise of the cold critical faculty more than this one. To a man of Pouchet's temperament the subject was full of danger—danger not lessened by the theoretical bias with which he approached it."

Pasteur's work in chemistry and in special research in fermentation had prepared him for this investigation. He knew more than Pouchet as to the insidious ways of microbes; he showed the weak point of his antagonist's experiments, and gained the prize offered in 1860 by the Academy, for "well-contrived experiments to throw new light upon the question of spontaneous generation." Pasteur threw light on the subject by his study of the organized particles—many of them living or dead bacteria—which float in the air. He opened twenty sealed flasks containing organic infusions in the pure air of the Mer de Glace, and only one thereafter showed signs of life; but eight out of twenty opened on the plains, and all of the twenty opened in town, developed germs. These and other experiments, carried out with a severity perfectly obvious to the instructed scientific reader, and accompanied by a logic equally severe, restored the conviction that, even in these lower reaches of the scale of being, life does not appear without the operation of antecedent life. Pasteur's brusque conclusion was that "spontaneous generation is a chimera."

These experiments by Pasteur laid the foundation for a long series of studies of micro-organisms by himself, Tyndall and others. Tyndall describes the famous experiment in which he proves that "not in the air, nor in the infusions, nor in anything continuous diffused through the air, but in discrete (organic) particles, suspended in the air and nourished by the infusions, we are to seek the cause of life" as follows: "Supposing an infusion intrinsically barren, but readily susceptible of putrefaction when exposed to common air, to be brought into contact with unilluminable air (air freed from dust particles), what would be the result? It would never putrefy. Let a condensed beam be sent through a large flash or bolthead containing common air. The track of the beam is seen within the flask—the dust revealing the light, and the light revealing the dust. Cork the flask, stuff its neck with cotton-wool, or simply turn its mouth downward and leave it undisturbed for a day or two. Examined afterward with the luminous beam, no track is visible; the light passes through the flask as through a vacuum. The floating matter has abolished itself, being now attached to the interior surface of the flask. Were it the object effectually to detain the dirt, that surface might be coated with some sticky substance. Here, then, without 'torturing' the air in any way, is a means of ridding it, or rather of enabling it to rid itself, of floating matter.

"We have now to devise a means," he continues, "of testing the action of such spontaneously purified air upon putrescible infusions. Wooden chambers, or cases, accordingly are constructed, having glass fronts, side-windows and back-doors. Through the bottoms of the chambers test-tubes pass air-tight; their open ends, for about one-fifth of the length of the tubes, being within the chambers. Provision is made for a free connection through sinuous channels between the inner and the outer air. Through such channels, tho open, no dust will reach the chamber. The top of each chamber is perforated by a circular hole two inches in diameter, closed air-tight by a sheet of india-rubber. This is pierced in the middle by a pin, and through the pinhole is pushed the shank of a long pipette, ending above in a small funnel. The shank also passes through a stuffing-box of cotton-wool moistened with glycerine; so that, tightly clasped by the rubber and wool, the pipette is not likely in its motions up and down to carry any dust into the chamber.

"The chamber is carefully closed and permitted to remain quiet for two or three days. Examined at the beginning by a beam sent through its windows, the air is found laden with floating matter, which in three days has wholly disappeared. To prevent its ever rising again, the internal surface of the chamber was at the outset coated with glycerine. The fresh but putrescible liquid is introduced into the six tubes in succession by means of the pipette. Permitted to remain without further precaution, every one of the tubes would putrefy and fill itself with life. The liquid has been in contact with the dust-laden air outside by which it has been infected, and the infection must be destroyed. This is done by plunging the six tubes into a bath of heated oil and boiling the infusion. The time requisite to destroy the infection depends wholly upon its nature. Two minutes' boiling suffices to destroy some contagia, whereas two hundred minutes' boiling fails to destroy others. After the infusion has been sterilized, the oil-bath is withdrawn, and the liquid, whose putrescibility has been in no way affected by the boiling, is abandoned to the air of the chamber.

"With such chambers I tested, in the autumn and winter of 1875-6, infusions of the most various kinds, embracing natural animal liquids, the flesh and viscera of domestic animals, game, fish and vegetables. More than fifty chambers, each with its series of infusions, were tested, many of them repeatedly. There was no shade of uncertainty in any of the results. In every instance we had, within the chamber, perfect limpidity and sweetness, which in some cases lasted for more than a year—without the chamber, with the same infusion, putridity and its characteristic smells. In no instance was the least countenance lent to the notion that an infusion derived by heat of its inherent life, and placed in contact with air cleansed of its visibly suspended matter, has any power to generate life anew.

"The argument is now to be clenched by an experiment which will remove every residue of doubt as to the ability of the infusions here employed to sustain life. We open the back doors of our sealed chambers, and permit the common air, with its floating particles, to have access to our tubes. For three months they have remained pellucid and sweet—flesh, fish and vegetable extracts purer than ever cook manufactured. Three days' exposure to the dusty air suffices to render them muddy, fetid, and swarming with infusorial life. The liquids are thus proved, one and all, ready for putrefaction when the contaminating agent is applied."

Many such experiments as these established beyond a doubt the fact that no known cause of spontaneous generation occurs under the present conditions of life. "Omne vivum e vivo" would correctly express the accepted view of the twentieth century biologists, provided it be translated "all life from life" under known existing conditions, but probably life from the lifeless in its first origin on this earth or elsewhere.

That all living matter existing to-day has descended directly from preëxisting living matter is the doctrine of "Biogenesis," the rival of the dethroned doctrine of "Abiogenesis." Observe that the doctrine of biogenesis refers simply to what is now happening and has been happening in all times of which we have strictly scientific records. The theory of biogenesis thus understood as the prevailing natural process will still stand, even if, as seems probable, some lucky physiological chemist succeeds in synthesizing, under artificial conditions, new living matter, entirely independent of preëxisting living matter. He will have done nothing more than repeat under unusual and artificially controlled conditions the processes which probably occurred when in the evolution of matter in the post-incandescent ages of the earth living proteid, progenitor of all future organisms, first came into existence. So far as the future succession of organisms on this earth is concerned, it cannot even be imagined that living matter synthesized in scientific laboratories will play any part. The law of biogenesis, now established as firmly as that of gravitation, may be expected to stand as the very rock of ages in the science of biology.

Such is in outline the story of one of the greatest fallacies with which modern science has had to deal. But, strange to say, the establishment of the truth of biogenesis, which directly is of little importance to man, has laid the foundation for practical researches of a most momentous kind. To Pasteur and the other great generals in the last battles against the theory of spontaneous generation is due the honor of the establishment of the new science of bacteriology which in the last two decades has come to play such a mighty part in the development of modern life.

CHAPTER V

THE MYSTERY OF THE CELL

In the two preceding chapters, living substance has been spoken of as existing in separate organic individuals, plants and animals. It is not known to exist in a mass not organized as an individual plant or animal. Many early philosophers did conceive of living matter as existing without individualization. Thus Oken (1805), in his Ur-Schleim theory, when he says that every organic thing came from primitive slime which originated in the sea from organic matter in the course of planetary evolution, simply repeated an idea passed down by the Greek philosopher Anaximenes and others.

Haeckel's theory of the Monera as the simplest of living things allies him to this belief. He says: "In the Monera, the simplest conceivable organisms, the whole body consists merely of plasm, corresponding to the 'primitive slime' of the earlier natural philosophers." And again, in "The Natural History of Creation," he describes the Monera as "simple, soft, albuminous lumps . . . without component parts, whose whole albuminous body is as homogeneous in itself as an inorganic crystal."

Huxley also for a time supported this view. In 1869 he described a peculiar sticky mud from the bottom of the Atlantic. The stickiness was apparently due to the presence of innumerable lumps of a transparent gelatinous substance without discoverable nuclei or membranous envelopes. Huxley interpreted this matter to be masses of protoplasm. He thought it a new form of the simple animate things (Monera) which had been described by Haeckel, and therefore named it Bathybius Haeckelii. Haeckel himself examined the mud and agreed with Huxley's interpretation. Later studies, however, convinced Huxley that the slime was in reality some sort of inorganic precipitate, and at the British Association meeting in 1879 he made a public renunciation of Bathybius.

Leaving this interesting historical conception of living matter in extensive undifferentiated masses, the idea of the individualization of living substance prevails in modern biological science. An organic individual is a unitary mass of living substance. Microscopic study of plants and animals shows them to be made up of these unitary masses —the cells. An illustration will make this point clear. Dissection shows that an organ of an animal's body is composed of several building materials, or tissues, such as muscular tissue, nervous tissue, bony tissue, etc. The microscopic study of these tissues reveals the fact that they are composed of small masses of protoplasm—the cells. Hence a plant or animal with several tissues is a multicellular organism. There are many simple plants and animals whose body consists of a single cell and these are called unicellular animals. Every such simple organism is an individual. The cell then is the lowest stage of individuality.

It is true, as will be explained in detail later, that the microscope reveals different structures in cells. Especially characteristic are the main body of the cell, the "cytoplasm," and the "nucleus" imbedded in it. This suggests the possibility that the cell is composed of still lower individuals. However, many studies have shown that neither nucleus nor cytoplasm can exist independently, and hence they cannot be regarded as unit masses or individuals. The cell is the lowest stage of individuality known to modern biology.

Looking at the organic world synthetically, the cell stands prominent in a scheme of the five stages of individuality found there.

Individuals of the first order are cells. They represent elementary organisms that are not composed of lower units capable of life. An example is any unicellular animal or plant.

Individuals of the second order are tissues. The tissues are associations of individuals of the first order, each one of which is like the others. Examples are the muscular and nervous tissues of an animal, the conducting and supporting tissues of a plant.

Individuals of the third order are organs. The organs are associations of various kinds of individuals of the second order. Examples are the stomach and heart of an animal, the leaf and root of a plant.

Individuals of the fourth order are complex organisms. These are associations of various individuals of the third order. Examples are common animals and plants, whose bodies consist of organs united.

Individuals of the fifth order are communities. The communities are associations of individuals of the fourth order.

It should be noted that an individual of a higher order consists of an assemblage of those of the next lower order. Thus communities consist of persons, persons of organs, organs of tissues, and tissues of cells. In the end all living individual plants and animals are composed of cells and the cell is the seat of those events the expression of which is life. The cell is the life unit, the elementary organism, or as Virchow has said, the vital elementary unit.

The realization that it is in the cell that the answers to the great problems of biology are to be found is quite modern. Nevertheless this fact has already profoundly modified many phases of the science of life. Professor Wilson of Columbia University, justly regarded as one of the foremost biologists who have worked at the problems of cytology, or the biology of cells, has well outlined the influence of the cell theory on modern biology. He says: "It was the cell-theory that first brought the structure of plants and animals under one point of view, by revealing their common plan of organization. It was through the cell-theory that Kölliker, Remak, Nägeli and Hoffmeister opened the way to an understanding of the nature of embryological development, and the law of genetic continuity lying at the basis of inheritance. It was the cell-theory again which, in the hands of Goodsir, Virchow and Max Schultze, inaugurated a new era in the history of physiology and pathology, by showing that all the various functions of the body, in health and in disease, are but the outward expression of cell-activities. And at a still later day it was through the cell-theory that Hertwig, Fol, Van Beneden and Strasburger solved the long-standing riddle of the fertilization of the egg and the mechanism of hereditary transmission. No other biological generalization, save only the theory of organic evolution, has brought so many apparently diverse phenomena under a common point of view or has accomplished more for the unification of knowledge. The cell-theory must, therefore, be placed beside the development-theory as one of the foundation stones of modern biology."

The history of the development of the idea that cells are the elementary units of living matter is essential to an understanding of present-day problems, and therefore a rapid survey of the important historical points may be made. These have been well traced by Oscar Hertwig, Professor at Berlin, in his famous "Die Zelle und die Gewebe." "The conception or idea connected with the word 'cell,' used scientifically," he says, "has been considerably altered during the last fifty years. The history of the various changes in this conception, or the history of the cell-theory, is of great interest, and nothing could be more suitable than to give a short account of this history in order to introduce the beginner to the series of conceptions connected with the word 'cells'; this, indeed, may prove useful in other directions. For while, on the one hand, we see how the conception of the cell which is at present accepted, has developed gradually out of older and less complete conceptions, we realize, on the other hand, that we cannot regard it as final or perfect; but on the contrary, we have every ground to hope that better and more delicate methods of investigation, due partly to improved optical instruments, may greatly add to our present knowledge, and may perhaps enrich it with a quite new series of conceptions.

"The theory that organisms are composed of cells was first suggested by the study of plant-structure. At the end of the seventeenth century the Italian, Marcellus Malpighi, and the Englishman, Grew, gained the first insight into the more delicate structure of plants; by means of low magnifying powers they discovered, in the first place, small room-like spaces, provided with firm walls, and filled with fluid, the cells; and in the second, various kinds of long tubes, which, in most parts, are embedded in the ground tissue, and which, from their appearance, are now called spiral ducts or vessels. Much greater importance, however, was attached to these facts after the investigations which were carried on in a more philosophical spirit by Bahn toward the end of the eighteenth century were published.

"Caspar Friedrich Wolff, Oken, and others, raised the question of the development of plants, and endeavored to show that the ducts and vessels originated in cells. Above all, Treviranus rendered important service by proving in his treatise, entitled 'Vom inwendigen Bau der Gewächse,' published in 1808, that vessels develop from cells.

"The study of the lowest plants has also proved of the greatest importance in establishing the cell-theory. Small algae were observed, which during their whole lifetime remain either single cells, or consist of simple rows of cells, easily to be separated from one another. Finally, the study of the metabolism of plants led investigators to believe that, in the economy of the plant, it is the cell which absorbs the nutrient substances, elaborates them, and gives them up in an altered form. Thus, at the beginning of the last century, the cell was recognized by many investigators as the morphological and physiological elementary unit of the plant."

These views, however, only obtained general acceptance after the year 1838, when M. Schleiden, who is so frequently cited as the founder of the cell-theory, published in Müller's "Archives" his famous paper, "Beiträge zur Phytogenesis." In this paper Schleiden endeavored to explain the mystery of cell-formation. He thought he had found the key to the difficulty in the discovery of the English botanist, R. Brown, who, in the year 1833, while making investigations upon orchids, discovered nuclei. Schleiden made further discoveries in this direction; he showed that nuclei are present in many plants, and as they are invariably found in young cells, the idea occurred to him that the nucleus must have a near connection with the mysterious beginning of the cell, and in consequence must be of great importance in its life-history.

The way in which Schleiden made use of this idea, which was based upon erroneous observations, to build up a theory of phytogenesis, must now be regarded as a mistake; on the other hand, it must not be forgotten that his perception of the general importance of the nucleus was correct up to a certain point, and that this one idea has in itself exerted an influence far beyond the narrow limits of the science of botany, for it is owing to this that the cell-theory was first applied to animal tissues. For it is just in animal cells that the nuclei stand out most distinctly from among all the other cell-contents, thus showing most evidently the similarity between the histological elements of plants and animals. Thus this little treatise of Schleiden's in 1838 marks an important historical turning-point, and since this time the most important work in the building up of the cell-theory has been done upon animal tissues.

Attempts to represent the animal body as consisting of a large number of extremely minute elements had been made before Schleiden's time, as is shown by the hypotheses of Oken, Heusinger, Raspail, and many other writers. However, it was impossible to develop these theories further, since they were based upon so many incorrect observations and false deductions that the good in them was outweighed by their errors.

Schwann, however, was the first to attempt to frame a really comprehensive cell-theory which should refer to all kinds of animal tissues. During the year 1838 Schwann, in the course of a conversation with Schleiden, was informed of the new theory of cell-formation, and of the importance which was attached to the nucleus in plant-cells. It immediately struck him, as he himself relates, that there are a great many points of resemblance between animal and vegetable cells. He therefore, with most praiseworthy energy, set on foot a comprehensive series of experiments, the results of which he published in 1839.

Thus Schwann originated a theory which, altho imperfect in many respects, yet is applicable both to plants and animals, and which, further, is easily understood, and in the main correct. According to this theory, every part of the animal body is either built up of elements, corresponding to the plant-cells, massed together, or is derived from such elements which have undergone certain metamorphoses. This theory has formed a satisfactory foundation upon which many further investigations have been based.

However, as has been mentioned already, the conception which Schleiden and Schwann formed of the plant and animal element was incorrect in many respects. They both defined the cell as a small vesicle, with a firm membrane enclosing fluid contents, that is to say as a small chamber, or "cellula," in the true sense of the word. They considered the membrane to be the most important and essential part of the vesicle, for they thought that in consequence of its chemico-physical properties it regulated the metabolism of the cell.

The series of conceptions which now associate with the word "cell" are, thanks to the great progress made during the last fifty years, essentially different from the above. Schleiden and Schwann's cell-theory has undergone a radical reform, having been superseded by the Protoplasmic theory, which is especially associated with the name of Max Schultze.

The History of the Protoplasmic theory is also of supreme interest. Even Schleiden observed in the plant-cell, in addition to the cell sap, a delicate transparent substance containing small granules; this substance he called plant slime. In the year 1846 Mohl called it Protoplasm, a name which has since become so significant, and which before had been used by Purkinje for the substance of which the youngest animal embryos are formed. Further, he presented a new picture of the living appearance of plant protoplasm; he discovered that it completely filled up the interior of young plant cells, and that in larger and older cells, it absorbed fluid, which collected into droplets or vacuoles. Finally, Mohl established the fact that protoplasm, as has been already stated by Schleiden about the plant slime, shows strikingly peculiar movements; these were first discovered in the year 1772 by Bonaventura Corti, and later in 1807 by C. L. Treviranus, and were described as "the circulatory movements of the cell-sap."

By degrees further discoveries were made, which added to the importance attached to these protoplasmic contents of the cell. In the lowest algae, as was observed by Cohn and others, the protoplasm draws itself away from the cell membrane at the time of reproduction, and forms a naked oval body, the swarm-spore, which lies freely in the cell cavity; this swarm-spore soon breaks down the membrane at one spot, after which it creeps out through the opening, and swims about in the water by means of its cilia, like an independent organism; but it has no cell membrane.

Similar facts were discovered through the study of the animal cell, which could not be reconciled with the old conception of the cell. A few years after the enunciation of Schwann's theory, various investigators, Kölliker, Bischoff and others, observed many animal cells in which no distinct membrane could be discovered, and in consequence a lengthy dispute arose as to whether these bodies were really without membranes, and hence not cells, or whether they were true cells. Further, movements similar to those seen in plant protoplasm were discovered in the granular ground substance of certain animal cells, such as the lymph corpuscles. In consequence Remak applied the term protoplasm, which Mohl had already made use of for plant cells, to the ground substance of animal cells.

Important insight into the nature of protoplasm was afforded by the study of the lowest organism, Rhizopoda (Amoebae), Myxomycetes, etc. Dujardin had called the slimy, granular, contractile substance of which they are composed "Sarcode." Subsequently, Max Schultze and de Bary proved, after most careful investigation, that the protoplasm of plants and animals and the sarcode of the lowest organisms are identical.

In consequence of these discoveries, investigators, such as Nägeli, Alexander Braun, Leydig, Kölliker, Cohn, de Bary, etc., considered the cell membrane to be of but minor importance in comparison to its contents; however, the credit is due to Max Schultze, above all others, of having made use of these later discoveries in subjecting the cell theory of Schleiden and Schwann to a searching critical examination, and of founding a protoplasmic theory. He attacked the former articles of belief, which it was necessary to renounce, in four excellent tho short papers, the first of which was published in the year 1860.

He based his theory that the cell-membrane is not an essential part of the elementary organisms of plants and animals on the following three facts: First, that a certain substance, the protoplasm of plants and animals, and the sarcode of the simplest forms, which may be recognized by its peculiar phenomena of movement, is found in all organisms; secondly, that altho as a rule the protoplasm of plants is surrounded by a special firm membrane, yet under certain conditions it is able to become divested of this membrane, and to swim about in water as in the case of naked swarm-spores; and finally, that animal cells and the lowest unicellular organisms very frequently possess no cell-membrane, but appear as naked protoplasm and naked sarcode. It is true that he retains the term "cell," which was introduced into anatomical language by Schleiden and Schwann; but he defines it as a small mass of protoplasm endowed with the attributes of life.

Hence it is evident that the term "cell" is incorrect. That it, nevertheless, has been retained, may be partly ascribed to a kind of loyalty to the vigorous combatants, who, as Brücke expresses it, conquered the whole field of histology under the banner of the cell-theory, and partly to the circumstance, that the discoveries which brought about the new reform were only made by degrees, and were only generally accepted at a time when, in consequence of its having been used for several decades of years, the word cell had taken firm root in the literature of the subject.

Since the time of Brücke and Max Schultze knowledge of the true nature of the cell has increased considerably. Great insight has been gained into the structure and the vital properties of the protoplasm, and in especial, knowledge of the nucleus, and of the part it plays in cell-multiplication, and in sexual reproduction, has recently made great advances. The earlier definition, "the cell is a little mass of protoplasm," must now be replaced by the following: "The cell is a little mass of protoplasm, which contains in its interior a specially formed portion, the nucleus."

It is evident from the preceding history of the cell-theory that the term "cell" is a biological misnomer; for cells only rarely assume the form implied by the word of hollow chambers surrounded by solid walls. The term is merely a historical survival of a word casually employed by the botanists of the seventeenth century to designate the cells of certain plant-tissues which, when viewed in section, give somewhat the appearance of a honeycomb. The cells of these tissues are, in fact, separated by conspicuous solid walls which were mistaken by

Schleiden, followed by Schwann, for their essential part. The living substance contained within the walls was at first overlooked or was regarded as a waste-product, a view based upon the fact that in many important plant-tissues such as cork or wood it may wholly disappear, leaving only the lifeless walls. Researches showed, however, that most living cells are not hollow but solid bodies, and that in many cases—for example, the colorless corpuscles of blood and lymph—they are naked masses of protoplasm not surrounded by definite walls. Thus it was proved that neither the vesicular form nor the presence of surrounding walls is an essential character, and that the cell-contents—*i.e.*, the protoplasm—must be the seat of vital activity.

Within the cell contents lies a body, usually of definite rounded form, known as the nucleus, and this in turn often contains one or more smaller bodies or nucleoli. By some of the earlier workers the nucleus was supposed to be, like the cell-wall, of secondary importance, and many forms of cells were described as being devoid of a nucleus ("cytodes" of Haeckel). Nearly all later researches have indicated, however, that the characteristic nuclear material, whether forming a single body or scattered in smaller masses, is always present, and that it plays an essential part in the life of the cell. Besides the presence of protoplasm and nucleus, no other structural features of the cell are yet known to be of universal occurrence.

"We may," says Wilson, "therefore still accept as valid the definition given more than thirty years ago by Leydig and Max Schultze, that a cell is a mass of protoplasm containing a nucleus, to which we may add Schultze's statement that both nucleus and protoplasm arise through the division of the corresponding elements of a preëxisting cell."

The form of cells is highly variable. In isolated cells, especially those floating freely in a fluid and not subjected to unequal pressure, the spherical form is common, but even such free cells may be modified in form by internal movements and differentiations of the cell-substance. For example, some egg-cells are spherical while others are ovoidal; muscle cells are elongated; nerve cells much branched; the white cells of the blood are irregular in shape because of their movements. But no matter how diverse the form of the cells, their structure is essentially the same.

As already suggested, a cell-wall or membrane is usually, tho not always present. Sometimes the cell-substance has no more of a limiting membrane than has a drop of oil floating in water, that is, there is simply an undifferentiated film separating it from its surroundings. The cell-mass of cell-substance consists of protoplasm, the active living substance, in which may be embedded granules of lifeless substances. If the term protoplasm is accepted as synonymous with living matter, then there is protoplasm both in the main body of the cell and also in the specially differentiated mass, most commonly central in position, known as the nucleus. It is convenient to call the protoplasm outside the nucleus "cytoplasm" and that within the nucleus the "karyoplasm" or "nucleoplasm."

In the cytoplasm there are various lifeless substances (metaplasm). Some of these, like fat and starch, are reserve food absorbed but not used by the cell, others, like pigment and the cell-wall, are the lifeless products of life activity. The amount of metaplasm is frequently vastly greater than the amount of protoplasm in a cell. For example, a hen's egg just before leaving the ovary is a cell about one inch in diameter (the yolk of the egg). A small white disk on the upper surface consists of concentrated protoplasm, but the greater part of this enormous egg-cell is made up of stored yolk (metaplasm) to be used as food by the chick in its development during incubation.

The nucleus is usually surrounded by a definite membrane, the nuclear membrane. Within this membrane and embedded in the general protoplasmic basis, there are granules or masses of a substance which has a strong affinity for certain chemical dyes, hence called "chromatin." When this chromatin is massed into rod-shaped bodies, as happens in the process of cell-division, the term "chromosomes" is applied to these masses of chromatin. Then, too, other bodies, nucleoli, are often present. Their nature is not clearly understood, probably because they are extremely variable.

Careful study of the nucleus during all its phases gives reason to believe that its structural basis is similar to that of the cell-body; and that during the course of cell-division, when the nuclear membrane usually disappears, cytoplasm and karyoplasm come into direct continuity. For these and other reasons the terms "nucleus" and "cell-body" should probably be regarded as only topographical expressions denoting two differentiated areas in a common structural basis. The terms, "karyoplasm" and "cytoplasm," possess, however, a specific significance owing to the fact that there is on the whole a definite chemical contrast between the nuclear substance and that of the cell-body, the former being characterized by the abundance of a substance rich in phosphorus known as "nuclein," while the latter contains no true nuclein and is especially rich in albuminous substances such as nucleoalbumins, albumins, globulins, and the like, which contain little or no phosphorus.

"Both morphologically and physiologically," said Wilson, "the differentiation of the active cell-substance into nucleus and cell-body must be regarded as a fundamental character of the cell because of its universal, or all but universal, occurrence, and because there is reason to believe that it is in some manner an expression of the dual aspect of the fundamental process of metabolism, constructive and destructive, that lies at the basis of cell life."

In addition to the cytoplasm or cell-body and the nucleus recent biologists believe that an extremely minute body lying just outside the nuclear membrane, and known as the "centrosome," is an essential element of the cell. The centrosome has been seen in a large number of cells, is known to play an important part in cell-division and in the fertilization of egg-shells and has been regarded by some cytologists as the "dynamic center" of the cell. So intricate are biological problems that the functions of the centrosome are far from being understood. Its structure has been fully studied, but interpretations differ. Some animal and plant-cells appear to differ so much from one another as to their form and contents, that, at first sight, they seem to have nothing in common, and hence it seems impossible to compare them. For instance, if a cell at the growing-point of a plant be taken and compared with one filled with starch granules from the tuber of a potato, or if the contents of an embryo cell from a germinal disk be compared with those of a fat cell, or of one from the egg of an Amphibian filled with yolk granules, the inexperienced observer sees nothing but contrasts. Nevertheless, all these exceedingly different cells are seen on closer examination to be similar in one respect—*i.e.*, in the possession of a very important, peculiar mixture of substances, which is sometimes present in large quantities, and sometimes only in traces, but which is never wholly absent in any elementary organism. In this mixture of substances the wonderful vital phenomena may very frequently be observed (contractility, irritability, etc.); and, moreover, since in young cells, in lower organisms, and in the cells of growing-points and germinal areas, it is in the cell-substance alone (the nucleus of course being excepted) that these properties have been observed, this substance has been recognized as the chief supporter of the vital functions. It is the protoplasm or "forming matter."

In order to know what protoplasm is, it is advisable to examine it in those cells in which it is present in large quantities, and in which it is as free as possible from admixture with other bodies; and among such the most suitable are those organisms from the study of which the founders of the protoplasmic theory formed their conception of the nature of this substance. Such organisms are young plant-cells, Amoebae, and the lymph corpuscles of vertebrates.

The protoplasm of unicellular organisms, and of plant and animal cells appears as a viscid substance, which is almost always colorless, which will not mix with water, and which, in consequence of a certain resemblance to slimy substances, was called by Schleiden the "slime of the cell." Its refractive power is greater than that of water, so that the most delicate threads of protoplasm, altho colorless, may be distinguished in this medium. Minute granules, the "microsomes," which look only like dots, are always present in greater or less numbers in all protoplasm, and may be seen with a low power of the microscope to be embedded in a homogeneous ground substance.

As to the very minute structure of protoplasm, "most of the earlier observers," says Wilson, "regarded the meshwork as a fibrillar structure, either forming a continuous network or reticulum somewhat like the fibrous network of a sponge or consisting of disconnected threads, whether simple or branching ('filar theory' of Flemming), and the same view is widely held at the present time. The meshwork has received various names in accordance with this conception, among which may be mentioned 'reticulum,' 'threadwork,' 'spongioplasm,' 'mitome,' 'filar substance,' all of which are still in use. Under this view the 'granules' described by Schultze, Virchow and still earlier observers have been variously regarded as nodes of the network, optical sections of the threads, or as actual granules ('microsomes') suspended in the network as described above."

Widely opposed to these views is the "alveolar theory" of Bütschli, which has won an increasing number of adherents. Bütschli regards protoplasm as having a foam-like alveolar structure ("Wabenstruktur"), nearly similar to that of an emulsion and he has shown in a series of beautiful experiments that artificial emulsions variously prepared, may show the microscope a marvelously close resemblance to living protoplasm, and further that drops of oil-emulsion suspended in water may even exhibit amoeboid changes of form.

The two (three) general views hereinbefore outlined may justly be designated respectively as the fibrillar (reticular or filar) and alveolar theories of protoplasmic structure, and each of them has been believed by some of its adherents to be universally applicable to all forms of protoplasm. Besides them may be placed, as a third general view, the granular theory especially associated with the name of Altmann, by whom it has been most fully developed, tho a number of earlier writers have held similar views. According to Altmann's view, which apart from its theoretical development approaches in some respects that of Bütschli, protoplasm is compounded of innumerable minute granules which alone form its essential active basis; and while fibrillar or alveolar structures may occur, these are of only secondary importance.

Which of these views is correct? The present tendency of cytologists is toward the conclusion that none of them is of universal application and that all exist under certain conditions. In support of this may be cited the studies of Professor Wilson, who has been led to the conclusion that "no universal formula for protoplasmic structure can be given. In that classical object, the echinoderm-egg, for example, it is easy to satisfy oneself, both in the living cell and in sections, that the protoplasm has a beautiful alveolar structure, exactly as described by Bütschli in the same object. This structure is here, however, entirely of secondary origin; for its genesis can be traced step by step during the growth of the ovarian eggs through the deposit of minute drops in a homogeneous basis, which ultimately gives rise to the interalveolar walls. In these same eggs the astral systems formed during their subsequent division are, I believe, no less certainly fibrillar; and thus we see the protoplasm of the same cell passing successively through homogeneous, alveolar, and fibrillar phases, at different periods of growth and in different conditions of physiological activity.

"There is good reason to regard this as typical of protoplasm in general. Bütschli's conclusions, based on research so thoro, prolonged and ingenious, are entitled to great weight; yet it is impossible to resist the evidence that fibrillar and granular as well as alveolar structures are of wide occurrence; and while each may be characteristic of certain kinds of cells, or of certain physiological conditions, none is common to all forms of protoplasm. If this position be well grounded, we must admit that the attempt to find in visible protoplasmic structure any adequate insight into its fundamental modes of physiological activity has thus far proved fruitless. We must rather seek the source of these activities in the ultramicroscopical organization, accepting the probability that apparently homogeneous protoplasm is a complex mixture of substances which may assume various forms of visible structure according to its modes of activity.

"Much discussion has been given to the question as to which of the visible elements of the protoplasm should be regarded as the 'living' substance proper. Later discussions have shown the futility of this discussion, which is indeed largely a verbal one, turning as it does on the sense of the word 'living.' In practice we continually use the word 'living' to denote various degrees of vital activity. Protoplasm deprived of nuclear matter has lost, wholly or in part, one of the most characteristic vital properties, namely, the power of synthetic metabolism; yet we still speak of it as 'living,' since it still retains for a longer or shorter period such properties as irritability and the power of coördinated movement; and, in like manner, various special elements of protoplasm may be termed 'living' in a still more restricted sense.

"In its fullest meaning, however, the word 'living' implies the existence of a group of coöperating activities more complex than those manifested by any one substance or structural element. I am, therefore, entirely in accord with the view urged by Sachs, Kölliker, Verworn, and other recent writers, that life can only be properly regarded as a property of the cell-system as a whole; and the separate elements of the system would, with Sachs, better be designated as 'active' or 'passive,' rather than as 'living' or 'lifeless.' Thus regarded, the distinction between 'protoplasmic' and 'metaplasmic' substances, while a real and necessary one, becomes after all one of degree."

CHAPTER VI

SEEING THE CREATURE GROW

Among the vital phenomena exhibited by cells and visible through the microscope, none is so strikingly distinctive of living matter as is the process of cell-division. Closely connected with it are some of the greatest problems of biology. By the continued division of an original germ-cell or egg-cell all the tissue cells of a multicellular animal arise and the germ-cell itself arises in the parent body from other cells by cell-division. Thus the problem is one of the central facts of development and inheritance.

The rapid advance of biological research is continually adding weight to the conclusions reached years ago that every cell originates by division of some preëxisting cell (Omnis cellula e cellula). This is now regarded as one of the fundamental laws of biology and obviously is a corollary of the biogenetic law spoken of which states that all living matter (known to exist only in cells) originates from preexisting living matter.

"How do cells originate?" was the problem which troubled the biologists of the early part of the nineteenth century. Schleiden and Schwann tried to answer the question, but their answer was entirely wrong. They held that cells, which they were fond of comparing to crystals, formed themselves like crystals in a mother-liquor. Schwann even went further, teaching that young cells developed, not only within the mother-cell (as propounded by Schleiden), but also outside of it, in an organic substance, which is frequently present in animal tissues as intercellular substance, and which he called also "Cytoblastem." Thus Schwann taught that cells were formed spontaneously both inside and outside of the mother-cell, which would be a genuine case of spontaneous generation from formless germ substance.

These were indeed grave fundamental errors, from which, however, the botanists were the first to extricate themselves. In the year 1846 a general law was formulated in consequence of the observations of Mohl, Unger, and above all, Nägeli. This law states that new plant cells only spring from those already present, and further that this occurs in such a manner, that the mother-cell becomes broken up by dividing into two or more daughter-cells. This was first observed by Mohl.

It was much more difficult to disprove the theory, that the cells of animal tissue arise from cytoblasts, and this was especially the case in the domain of pathological anatomy, for it was thought that the formation of tumors and pus could be traced back to cytoblasts. At last, after many mistakes, more light was thrown upon the subject of the genesis of cells in the animal kingdom also, until finally the cytoblastic theory was absolutely disproved by Virchow, who originated the formula, "Omnis cellula e cellula." No spontaneous generation of cells occurs either in plants or animals. The many millions of cells of which, for instance, the body of a vertebrate animal is composed, have been produced by the repeated division of one cell, the ovum, in which the life of every animal commences.

The older histologists were unable to discover what part the nucleus played in cell-division. For many decades two opposing theories were held, of which now one and now the other obtained temporarily the greater number of supporters. According to the one theory, which was held by most botanists, the nucleus at each division was supposed to break up and become diffused throughout the protoplasm, in order to be formed anew in each daughter-cell. According to the other, the nucleus was supposed to take an active part in the process of cell-division, and, at the commencement of it, to become elongated and constricted at a point, corresponding with the plane of division which is seen later, and to divide into halves, which separate from one another and move apart.

Later discoveries (1873-1880) revealed the extremely interesting formations and metamorphoses, which are seen in the nucleus during cell-division. These investigations have all pointed to the same conclusion, that the nucleus is a permanent and most important organ of the cell, and that it evidently plays a distinct rôle in the cell life during division. Just as the cell is never spontaneously generated, but is produced directly by the division of another cell, so the nucleus is never freshly created, but is derived from the constituent particles of another nucleus. The formula "omnis cellula e cellula" might be extended by adding "omnis nuclei e nucleo."

Since about 1876 it has been recognized that there are two widely different types of cell-division. In one type there appears to be a simple constriction of the nucleus and cell-body. This is known as "direct," "akinetic" or "amitotic" division. The second type is vastly more complicated, as will be described. To this are now applied the terms "direct division," "karyokinesis" or "mitosis." The terms mitosis and amitosis (referring to the presence or absence of chromosomes in the dividing cells) are preferred by most biologists.

As to the occurrence of these two types, modern research has demonstrated the fact that amitosis or direct division, regarded by Remak and his immediate followers as of universal occurrence, is in reality a rare and exceptional process; and there is reason to believe, furthermore, that it is especially characteristic of highly specialized cells incapable of long-continued multiplication or such as are in the early stages of degeneration, for instance, in glandular epithelia and in the cells of transitory embryonic envelopes, where it is of frequent occurrence. Whether this view be well founded or not, it is certain that in all the higher and in many of the lower forms of life, indirect division or mitosis is the typical mode of cell-division. It is by mitotic division that the germ-cells arise and are prepared for their union during the process of maturation, and by the same process the oösperm segments and gives rise to the tissue-cells. It occurs not only in the highest forms of plants and animals, but also in such simple forms as the rhizopods, flagellates and diatoms. It may, therefore, be justly regarded as the most general expression of the "eternal law of continuous development" on which Virchow insisted.

The phenomena which occur during the process of mitosis are very varied and very complicated; nevertheless they conform to certain laws which are wonderfully constant in both plants and animals. The main feature of the process consists in this, that the various substances which are present in the resting nucleus, undergo a definite change of position, and the nuclear membrane being dissolved, enter into closer union with the cytoplasmic substance.

During this process the whole mass of chromatin in the nucleus becomes transformed into fine thread-like segments, the chromosomes, the number of which remains constant for each species of plant or animal. These chromosomes are arranged in a characteristic manner on a spindle-like structure of achromatic material extending between the two centrosomes. Each chromosome then divides longitudinally into two daughter chromosomes which for a time lie parallel with each other and are closely connected. Next, these daughter chromosomes separate into two groups, dividing themselves equally between the two groups to form the foundation of the daughter nuclei. The cell itself meanwhile becomes divided in such a way that each of the two cells formed by the division possesses one of the daughter nuclei.

The manner in which these changes are brought about is so interesting that it seems wise to give a more detailed outline of the process. Professor Wilson, in "The Cell in Development and Inheritance" gives a description in essentials as follows:

"In the present state of knowledge it is somewhat difficult to give a connected general account of mitosis, owing to the uncertainty that hangs over the nature and functions of the centrosome. For the purpose of the following preliminary outline, we shall take as a type mitosis in which a distinct and persistent centrosome is present, as has been mostly clearly determined in the maturation and cleavage of various animal eggs, and in the division of the testis-cells.

"In such cases the process involves three parallel series of changes, which affect the nucleus, the centrosome and the cytoplasm of the cell-body respectively. For descriptive purposes it may conveniently be divided into a series of successive stages or phases, which, however, graduate into one another and are separated by no well-defined limits. These are: (1) The 'Prophases,' or preparatory changes; (2) the 'Metaphase,' which involves the most essential step in the division of the nucleus; (3) the 'Anaphases,' in which the nuclear material is distributed; (4) the 'Telophases,' in which the entire cell divides and the daughter-cells are formed.

1. Prophases.—As the cell prepares for division, the most conspicuous fact is a transformation of the nuclear substance, involving both physical and chemical changes. The chromatin-substance rapidly increases in staining-power, loses its net-like arrangement and finally gives rise to a definite number of separate intensely staining bodies, usually rod-shaped, known as chromosomes. As a rule this process takes place as follows: The chromatin resolves itself little by little into a more or less convoluted thread, known as the skein or spireme, and its substance stains far more intensely than that of the reticulum. The spireme-thread is at first fine and closely convoluted, forming the 'close spireme.' Later the thread thickens and shortens and the convolution becomes more open.

"In some cases there is but a single continuous thread, in others the thread is from its first appearance divided into a number of separate pieces or segments, forming a segmented spireme. In either case it ultimately breaks transversely to form the chromosomes, which in most cases have the form of rods, straight or curved, tho they are sometimes spherical or ovoidal and in certain cases may be joined together in the form of rings. The staining-power of the chromatin is now at a maximum. As a rule the nuclear membrane meanwhile fades away and finally disappears, tho there are some cases in which it persists more or less completely through all the phases of division. The chromosomes now lie naked in the cell and the ground-substance of the nucleus becomes continuous with the surrounding cytoplasm.

"The remarkable fact has now been established with high probability that every species of plant or animal has a fixed and characteristic number of chromosomes, which regularly occurs in the division of all of its cells and in all forms arising by sexual reproduction the number is even. Thus in some of the sharks the number is thirty-six; in the mouse, the salamander, the trout, the lily, twenty-four; in the ox, guinea-pig and in man the number is said to be sixteen and the same number is characteristic of the onion. In the grasshopper it is twelve. Under certain conditions the number of chromosomes may be less than the normal in a given species, but these variations are only apparent exceptions.

"The nucleoli differ in their behavior in different cases. True nucleoli or plasmosomes sooner or later disappear, and the greater number of observers agree that they do not take part in the chromosome-formation.

"Meanwhile more or less nearly parallel with these changes in the chromatin a complicated structure known as the amphiaster makes its appearance in the position formerly occupied by the nucleus. This structure consists of a fibrous spindle-shaped body, the spindle, at either pole of which is a star or aster formed of rays or astral fibers radiating into the surrounding cytoplasm, the whole strongly suggesting the arrangement of iron filings in the field of a horseshoe magnet. The center of each aster is occupied by a minute body, known as the centrosome (Boveri, '88), which may be surrounded by a spherical mass known as the centrosphere (Strasburger, '93). As the amphiaster forms the chromosomes group themselves in a plane passing through the equator of the spindle, and thus form what is known as the equatorial plate.

"The entire structure, resulting from the foregoing changes, is known as the karyokinetic or mitotic figure. It may be described as consisting of two distinct parts, namely, the chromatic figure, formed by the deeply staining chromosomes; and the achromatic figure, consisting of the spindle and asters which in general stain but slightly.

"2. Metaphase.—The prophases of mitosis are, on the whole, preparatory in character. The metaphase, which follows, forms the initial phase of actual division. Each chromosome splits lengthwise into two exactly similar halves, which afterward diverge to opposite poles of the spindles, and here each group of daughter-chromosomes finally gives rise to a daughter-nucleus. In some cases the splitting of the chromosomes cannot be seen until they have grouped themselves in the equatorial plane of the spindle, and it is only in this case that the term 'metaphase' can be applied to the mitotic figure as a whole.

"In a large number of cases, however, the splitting may take place at an earlier period in the spireme-stage or even in a few cases in the reticulum of the mother-nucleus. Such variations do not, however, affect the essential fact that the chromatic network is converted into a thread which, whether continuous or discontinuous, splits throughout its entire length into two exactly equivalent halves. The splitting of the chromosomes, discovered by Flemming in 1880, is the most significant and fundamental operation of cell-division, for by it, as Roux first pointed out ('83), the entire substance of the chromatic network is precisely halved and the daughter-nuclei receive precisely equivalent portions of chromatin from the mother-nucleus. It is very important to observe that the nuclear division always shows this exact quality, whether division of the cell-body be equal or unequal.

"3. Anaphases.—After splitting of the chromosomes, the daughter-chromosomes, arranged in two corresponding groups, diverge to opposite poles of the spindle, where they become closely crowded in a mass near the center of the aster. As they diverge the two groups of daughter-chromosomes are connected by a bundle of achromatic fibers, stretching across the interval between them and known as the interzonal fibers or connecting fibers. In the division of plant cells and often in that of animal cells these fibers show during this period a series of deeply staining thickenings in the equatorial plane forming the cell-plate or mid-body.

"4. Telophases.—In the final phases of mitosis the entire cell is divided in two in a plane passing through the equator of the spindle, each of the daughter-cells receiving a group of chromosomes, half of the spindle and one of the asters with its centrosome. Meanwhile a daughter-nucleus is reconstructed in each cell from the group of chromosomes it contains. When first formed the daughter-nuclei are of equal size. If, however, division of the cell-body has been unequal, the nuclei become, in the end, correspondingly unequal, a fact which, as Conklin and others have pointed out, proves that the size of the nucleus is controlled by that of the cytoplasmic mass in which it lies.

"The fate of the achromatic structures varies considerably and has been accurately determined in only a few cases. As a rule the spindle fibers disappear more or less completely, but a portion of their substance sometimes persists in a modified form. In dividing plant cells the cell plate finally extends across the entire cell and splits into two layers, between which appears the membrane by which the daughter-cells are cut apart. A nearly similar process occurs in a few animal cells, but as a rule the cell-plate is here greatly reduced and forms no membrane, the cell dividing by constriction through the equatorial plane."

Such is a general description of mitosis. The variations from the type, the origin and fate of the various structures taking part in the division, their relation to each other and the mechanism by means of which the chromosomes divide and separate to form the new nuclei are interesting problems which are to-day being subjected to keen investigation in the laboratories of the cytologists. But most interesting of all perhaps is the problem of the chromosomes in relation to inheritance. This problem will be more fully discussed in the chapter on Heredity.

Some of the most important studies on the physiological relations of nucleus and cytoplasm have been made with one-celled animals. Brandt in 1877 and Nussbaum in 1884 cut certain protozoons into pieces and observed that pieces containing nuclear matter quickly regenerate and produce perfect animals, while the enucleated fragments soon die. One of the most remarkable animals with this power to regenerate is the trumpet animalcule Stentor. Gruber in 1885 found that when this animalcule was fragmented, pieces possessing a large fragment of the nucleus completely regenerated within twenty-four hours. If the nuclear fragment were smaller, the regeneration proceeded more slowly. If no nuclear substance were present, no regeneration took place, tho the wound closed and the fragment lived for a considerable time.

The only exception—but it is a very significant one—was the case of individuals in which the process of normal fission had begun. In these a non-nucleated fragment in which the formation of a new peristome had already been initiated healed the wound and completed the formation of the peristome. Lillie (1896) has recently found that Stentor may by shaking be broken into fragments of all sizes and that nucleated fragments as small as one-twenty-seventh the volume of the entire animal are still capable of complete regeneration, non-nucleated fragments perish.

Many other such experiments on one-celled animals show that life for a considerable period, perfectly normal movements, susceptibility to stimulus and the power of taking food may continue in enucleated parts of unicellular animals. They lack, however, the power of digestion and secretion and hence cannot continue to live as do the nucleated parts. These facts demonstrate that the nucleus plays an important part in metabolism. Experiments on plants have supported this conclusion. It will be noted that if a unicellular organism be divided into two parts, the part with the nucleus is a complete cell (a mass of protoplasm with a nucleus), while the other part possesses no longer the individuality of a cell and perishes.

It is well known that all animals and plants have a definite limit of growth. From the cytological point of view the limit of body-size appears to be correlated with the total number of cells formed rather than with their individual size. This relation has been carefully studied by Conklin ('96) in the case of the gasteropod Crepidula, an animal which varies greatly in size in the mature condition, the dwarfs having in some cases not more than one-twenty-fifth the volume of the giants. The eggs are, however, of the same size in all and their number is proportional to the size of the adult. The same is true of the tissue-cells. Measurements of cells from the epidermis, the kidney, the liver, the alimentary epithelium and other tissues show that they are on the whole as large in the dwarfs as in the giants. The body-size therefore depends on the total number of cells rather than on their size, individually considered, and the same appears to be the case in plants.

It is in the cells of both plant and animal organisms that the vital functions are carried on. All the vital processes of a complex animal appear to be nothing but the highly developed result of the individual vital processes of its innumerable variously functioning cells. The study of the processes of digestion, of the changes in muscle and nerve cells leads finally to the examination of the functions of gland, muscle, ganglion and brain.

CHAPTER VII

ORGANIC FUNCTIONS

THE facts dealing with the physiology of organisms, the activities associated with that which we call life are often designated Organic Functions. The terms animal physiology, plant physiology and human physiology are in common use and often suggest to the lay reader that the functions or workings of the organs of plants, animals or man are quite distinct, so much so as to require discussion in different treatises. This is true only as a matter of detail, for in the past fifty years it has been made evident that in general principles all living things are fundamentally similar. One of the most important summaries of this similarity is Huxley's famous essay, "The Border Territory Between the Animal and Vegetable Kingdoms," written in 1876, extracts from which follow.

In the second edition of the "Règne Animal," published in 1828, Cuvier devotes a special section to the "Division of Organized Beings into Animals and Vegetables," in which the question is treated with that comprehensiveness of knowledge and clear critical judgment which characterize his writings and justify biologists in regarding them as representative expressions of the most extensive, if not the profoundest, knowledge of his time. He affirms that living beings have been subdivided from the earliest times into animated beings, which possess sense and motion, and inanimated beings, which are devoid of these functions and simply vegetable.

Altho the roots of plants direct themselves toward moisture and their leaves toward air and light, altho the parts of some plants exhibit oscillating movements without any perceptible cause and the leaves of others retract when touched, yet none of these movements justify the ascription to plants of perception of will. From the mobility of animals Cuvier, with his characteristic partiality for teleological reasoning, reduces the necessity of the existence in them of an alimentary cavity, or reservoir of food, whence their nutrition may be drawn by vessels, which are a sort of internal roots; and, in the presence of this alimentary cavity he naturally sees the primary and the most important distinction between animals and plants. Logical reasoning deduces the necessity of the existence in them of an alimentary cavity, or reservoir of food, whence their nutrition may be drawn by the vessels, which are a sort of internal roots; and in the presence of this alimentary cavity he naturally sees the primary and the most important distinction between animals and plants.

Following out his teleological argument, Cuvier remarks that the organization of this cavity and its appurtenances must needs vary according to the nature of the ailment and the operations which it has to undergo before it can be converted into substances fitted for absorption, while the atmosphere and the earth supply plants with juices ready prepared and which can be absorbed immediately. As the animal body required to be independent of heat and of the atmosphere, there were no means by which the motion of its fluids could be produced by internal causes. Hence arose the second great distinctive character of animals, or the circulatory system, which is less important than the digestive, since it was unnecessary, and therefore is absent, in the more simple animals.

Animals further needed muscles for locomotion and nerves for sensibility. Hence, says Cuvier, it was necessary that the chemical composition of the animal body should be more complicated than that of the plant; and it is so, inasmuch as an additional substance—nitrogen—enters into it as an essential element; while in plants nitrogen is only accidentally joined with the three other fundamental constituents of organic beings—carbon, hydrogen and oxygen. Indeed, he afterward affirms that nitrogen is peculiar to animals, and herein he places the third distinction between the animal and the plant. The soil and the atmosphere supply plants with water composed of hydrogen and oxygen and carbonic acid containing carbon and oxygen. They retain the hydrogen and the carbon, exhale the superfluous oxygen and absorb little or no nitrogen. The essential character of vegetable life is the exhalation of oxygen, which is effected through the agency of light. Animals, on the contrary, derive their nourishment either directly or indirectly from plants. They get rid of the superfluous hydrogen and carbon and accumulate nitrogen. The relations of plants and animals to the atmosphere are therefore inverse. The plant withdraws water and carbonic acid from the atmosphere, the animal contributes both to it. Respiration—that is, the absorption of oxygen and the exhalation of carbonic acid—is the specially animal function of animals and constitutes their fourth distinctive character.

Thus wrote Cuvier in 1828. But in the fourth and fifth decades of this century the greatest and most rapid revolution which biological science has ever undergone was effected by the application of the modern microscope to the investigation of organic structure, by the introduction of exact and easily manageable methods of conducting the chemical analysis of organic compounds and finally by the employment of instruments of precision for the measurement of the physical forces which are at work in the living economy.

That semi-fluid contents (which we now term protoplasm) of the cells of certain plants, such as the Charae, are in constant and regular motion was made out by Bonaventura Corti a century ago; but the fact, important as it was, fell into oblivion and had to be rediscovered by Treviranus in 1807. Robert Brown noted the more complex motions of the protoplasm in the cells of Tradescantia in 1831, and now such movements of the living substance of plants are well known to be some of the most widely prevalent phenomena of vegetable life.

Agardh and other of the botanists of Cuvier's generation who occupied themselves with the lower plants had observed that, under particular circumstances, the contents of the cells of certain water-weeds were set free and moved about with considerable velocity and with all the appearances of spontaneity as locomotive bodies, which from their similarity to animals of simple organization, were called "zoospores." Even as late as 1845, however, a botanist of Schleiden's eminence dealt very skeptically with these statements, and his skepticism was the more justified since Ehrenberg in his elaborate and comprehensive work on the infusoria, had delared the greater number of what are now recognized as locomotive plants to be animals.

"At the present day," writes Huxley, "innumerable plants and free plant cells are known to pass the whole or part of their lives in an actively locomotive condition, in nowise distinguishable from that of one of the simpler animals, and while in this condition their movements are, to all appearances, as spontaneous—as much the product of volition—as those of such animals.

"Hence the teleological argument for Cuvier's first diagnostic character—the presence in animals of an alimentary cavity, or internal pocket, in which they can carry about their nutriment—has broken down, so far, at least, as his mode of stating it goes. And, with the advance of microscopic anatomy, the universality of the fact itself among animals has ceased to be predicable. Many animals of even complex structure which live parasitically within others are wholly devoid of an alimentary cavity. Their food is provided for them, not only ready cooked but ready digested, and the alimentary canal, become superflous, has disappeared, and, again, the males of most Rotifers have no digestive apparatus. Finally amid the lowest forms of animal life the speck of gelatinous protoplasm, which constitutes the whole body, has no permanent digestive cavity or mouth, but takes in its food anywhere and digests, so to speak, all over its body.

"But altho Cuvier's leading diagnosis of the animal from the plant will not stand a strict test, it remains one of the most constant of the distinctive characters of animals. And if we substitute for the possession of an alimentary cavity the power of taking solid nutriment into the body and there digesting it, the definition so changed will cover all animals, except certain parasites, and the few and exceptional cases of non-parasitic animals which do not feed at all. On the other hand, the definition thus amended will exclude all ordinary vegetable organisms. Cuvier himself practically gives up his second distinctive mark when he admits that it is wanting in the simpler animals.

"The third distinction is based on a completely erroneous conception of the chemical differences and resemblances between the constituents of animal and vegetable organisms, for which Cuvier is not responsible, as it was current among contemporary chemists. It is now established that nitrogen is as essential a constituent of vegetable as of animal living matter and that the latter is, chemically speaking, just as complicated as the former. Starchy substances, cellulose and sugar, once supposed to be exclusively confined to plants, are now known to be regular and normal products of animals. Amylaceous and saccharine substances are largely manufactured, even by the highest animals. Cellulose is widespread as a constituent of the skeletons of the lower animals and it is probable that amyloid substances are universally present in the animal organism, tho not in the precise form of starch.

"Moreover, altho it remains true that there is an inverse relation between the green plant in sunshine and the animal, in so far as under these circumstances the green plant decomposes carbonic acid and exhales oxygen while the animal absorbs oxygen and exhales carbonic acid, yet the exact researches of the modern chemical investigators of the physiological processes of plants have clearly demonstrated the fallacy of attempting to draw any general distinction between animals and vegetables on this ground. In fact, the difference vanishes with the sunshine, even in the case of the green plant, which in the dark absorbs oxygen and gives out carbonic acid like any animal. On the other hand, those plants, such as the fungi, which contain no chlorophyll and are not green, are always, so far as respiration is concerned, in the exact position of animals. They absorb oxygen and give out carbonic acid. Thus, by the progress of knowledge, Cuvier's fourth distinction between the animal and the plant has been as completely invalidated as the third and second, and even the first can be retained only in a modified form and subject to exceptions."

But has the advance of biology simply tended to break down old distinctions without establishing new ones? With a qualification, to be considered presently, the answer to this question is undoubtedly in the affirmative. The famous researches of Schwann and Schleiden in 1837 and the following years founded the modern science of histology or that branch of anatomy which deals with the ultimate visible structure of organisms as revealed by the microscope, and from that day to this the rapid improvement of methods of investigation and the energy of a host of accurate observers have given greater and greater breadth and firmness to Schwann's great generalization that a fundamental unity of structure obtains in animals and plants, and that, however diverse may be the fabrics or tissues of which their bodies are composed, all these varied structures result from the metamorphosis, or morphological units (termed cells in a more general sense than that in which the word "cells" was at first employed), which are not only similar in animals and in plants respectively, but present a close resemblance when those of animals and those of plants are compared together.

"The contractility which is the fundamental condition of locomotion," continues Huxley, "has not only been discovered to exist far more widely among plants than was formerly imagined, but in the plants the act of contraction has been found to be accompanied, as Dr. Burdon Sanderson's interesting investigations have shown, a disturbance of the electrical state of the contractile substance comparable to that which was found by Du Bois Reymond to be a concomitant of the activity of ordinary muscle in animals. Again, I know of no test by which the reaction of the leaves of the Sundew and of other plants to stimuli, so fully and carefully studied by Mr. Darwin, can be distinguished from those acts of contraction following upon stimuli, which are called "reflex" in animals.

"On each lobe of the bilobed leaf of Venus flytrap are three delicate filaments which stand out at right angles from the surface of the leaf. Touch one of them with the end of a fine human hair and the lobes of the leaf instantly close together in virtue of an act of contraction of part of their substance, just as the body of a snail contracts into its shell when one of its "horns" is irritated.

"The reflex action of the snail is the result of the presence of a nervous system in the animal. A molecular change takes place in the nerve of the tentacle, is propagated to the muscles by which the body is retracted, and causing them to contract, the act of retraction is brought about. Of course the similarity of the acts does not necessarily involve the conclusion that the mechanism by which they are effected is the same, but it suggests a suspicion of their identity which needs careful testing."

The results of inquiries into the structure of the nervous system of animals converge toward the conclusion that the nerve fibers, which have been regarded as ultimate elements of nervous tissue, are not such, but are simply the visible aggregations of vastly more attenuated filaments, the diameter of which dwindles down to the limits of our present microscopic vision, greatly as these have been extended by modern improvements of the microscope, and that a nerve is, in its essence, nothing but a linear tract of specially modified protoplasm between two points of an organism—one of which is able to affect the other by means of the communication so established. Hence it is conceivable that even the simplest living being may possess a nervous system. And the question whether plants are provided with a nervous system or not thus acquires a new aspect and presents the histologist and physiologist with a problem of extreme difficulty, which must be attacked from a new point of view and by the aid of methods which have yet to be invented.

"Thus it must be admitted," he says again, "that plants may be contractile and locomotive; that, while locomotive, their movements may have as much appearance of spontaneity as those of the lowest animals, and that many exhibit actions comparable to those which are brought about by the agency of a nervous system in animals. And it must be allowed to be possible that further research may reveal the existence of something comparable to a nervous system in plants. So that I know not where we can hope to find any absolute distinction between animals and plants, unless we return to their mode of nutrition and inquire whether certain differences of a more occult character than those imagined to exist by Cuvier, and which certainly hold good for the vast majority of animals and plants, are of universal application.

"A bean may be supplied with water in which salts of ammonia and certain other mineral salts are dissolved in due proportion, with atmospheric air containing its ordinary minute dose of carbonic acid and with nothing else but sunlight and heat. Under these circumstances, unnatural as they are, with proper management, the bean will thrust forth its radicle and its plumule; the former will grow down into roots, the latter grow up into the stem and leaves of a vigorous bean-plant, and this plant will, in due time, flower and produce its crop of beans just as if it were grown in the garden or in the field.

"The weight of the nitrogenous protein compounds, of the oily, starchy, saccharine and woody substances contained in the full-grown plant and its seeds will be vastly greater than the weight of the same substances contained in the bean from which it sprang. But nothing has been supplied to the bean save water, carbonic acid, and ammonia, potash, lime, iron and the like in combination with phosphoric, sulphuric and other acids. Neither protein, nor fat, nor starch, nor sugar, nor any substance in the slightest degree resembling them has formed part of the food of the bean. But the weights of the carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur and other elementary bodies contained in the bean-plant and in the seeds which it produces are exactly equivalent to the weights of the same elements which have disappeared from the materials supplied to the bean during its growth. Whence it follows that the bean has taken in only the raw materials, of its fabric and has manufactured them into bean-stuffs.

"The bean has been able to perform this great chemical feat by the help of its green coloring matter, or chlorophyll, for it is only the green parts of the plant which, under the influence of sunlight, have the marvelous power of decomposing carbonic acid, setting free the oxygen and laying hold of the carbon which it contains. In fact, the bean obtains two of the absolutely indispensable elements of its substance from two distinct sources. The watery solution, in which its roots are plunged, contains nitrogen but no carbon; the air, to which the leaves are exposed contains carbon, but its nitrogen is in the state of a free gas, in which condition the bean can make no use of it, and the chlorophyll is the apparatus by which the carbon is extracted from the atmospheric carbonic acid, the leaves being the chief laboratories in which this operation is effected.

"The great majority of conspicuous plants are, as everybody knows, green, and this rises from the abundance of their chlorophyll. The few which contain no chlorophyll and are colorless are unable to extract the carbon which they require from atmospheric carbonic acid and lead a parasitic existence upon other plants, but it by no means follows, often as the statement has been repeated, that the manufacturing power of plants depends on their chlorophyll and its interaction with the rays of the sun. On the contrary, it is easily demonstrated, as Pasteur first proved, that the lowest fungi, devoid of chlorophyll or of any substitute for it as they are, nevertheless possess the characteristic manufacturing power of plants in a very high degree. Only it is necessary that they should be supplied with a different kind of raw material; as they cannot extract carbon from carbonic acid, they must be furnished with something else that contains carbon. Tartaric acid is such a substance, and if a single spore of the commonest and most troublesome of molds—"Penicillium"—be sown in a saucerful of water in which tartrate of ammonia, with a small percentage of phosphates and sulphates is contained, and kept warm, whether in the dark or exposed to light, it will in a short time give rise to a thick crust of mold, which contains many million times the weight of the original spore in protein compounds and cellulose. Thus we have a very wide basis of fact for the generalization that plants are essentially characterized by their manufacturing capacity—by their power of working up mere mineral matters into complex organic compounds.

"Contrariwise, there is a no less wide foundation for the generalization that animals, as Cuvier put it, depend directly or indirectly upon plants for the material of their bodies; that is, either they are herbivorous or they eat other animals which are herbivorous. But for what constituents of their bodies are animals thus dependent upon plants? Certainly not for their horny matter; nor for chondrin, the proximate chemical element of cartilage; nor for gelatin; nor for syntonin, the constituent of muscle; nor for their nervous or biliary substances; nor for their amyloid matters; nor, necessarily, for their fats.

"It can be experimentally demonstrated that animals can make these for themselves. But that which they cannot make, but must in all known cases obtain directly or indirectly from plants, is the peculiar nitrogenous matter, protein. Thus the plant is the ideal proletariat of the living world—the worker who produces—the animal, the ideal aristocrat, who mostly occupies himself in consuming, after the manner of that noble representative of the line of Zähdarm, whose epitaph is written in 'Sartor Resartus.'

"Here is our last hope of finding a sharp line of demarcation between plants and animals, for, as I have already hinted, there is a border territory between the two kingdoms, a sort of no man's land, the inhabitants of which certainly cannot be discriminated and brought to their proper allegiance in any other way.

"Some months ago Professor Tyndall asked me to examine a drop of infusion of hay, placed under an excellent and powerful microscope, and to tell him what I thought some organisms visible in it were. I looked and observed, in the first place multitudes of 'Bacteria' moving about with their ordinary intermittent spasmodic wriggles. As to the vegetable nature of these, there is now no doubt. Not only does the close resemblance of the 'Bacteria' to unquestionable plants, such as the 'Oscillartoria' and the lower forms of 'Fungi,' justify this conclusion, but the manufacturing test settles the question at once. It is only needful to add a minute drop of fluid containing 'Bacteria' to water in which tartrate, phosphate and sulphate of ammonia are dissolved, and in a very short space of time the clear fluid becomes milky by reason of their prodigious multiplication which, of course, implies the manufacture of living bacterium-stuff out of these merely saline matters.

"But other active organisms, very much larger than the bacteria, attaining, in fact, the comparatively gigantic dimensions of one-three-thousandth of an inch or more, incessantly crossed the field of view. Each of these had a body shaped like a pear, the small end being slightly incurved and produced into a long curved filament, or cilium, of extreme tenuity. Behind this, from the concave side of the incurvation, proceeded another long cilium, so delicate as to be discernible only by the use of the highest powers and careful management of the light. In the center of the pear-shaped body a clear, round space could occasionally be discerned, but not always, and careful watching showed that this clear vacuity appeared gradually and then shut up and disappeared suddenly at regular intervals. Such a structure is of common occurrence among the lowest plants and animals and is known as a contractile vacuole.

"The little creature thus described sometimes propelled itself with great activity, with a curious rolling motion, by the lashing of the front cilium, while the second cilium trailed behind; sometimes it anchored itself by the hinder cilium and was spun around by the working of the other, its motions resembling those of an anchor buoy in a heavy sea. Sometimes, when two were in full career toward one another, each would appear dexterously to get out of the other's way; sometimes a crowd would assemble and jostle one another with as much semblance of individual effort as a spectator on the Grands Mulets might observe with a telescope among the specks representing men in the valley of Chamouni.

"The spectacle, tho always surprising, was not new to me. So my reply to the question put to me was that these organisms were what biologists call 'Monads,' and tho they might be animals, it was also possible that they might, like the 'Bacteria,' be plants. My friend received my verdict with an expression which showed a sad want of respect for authority. He would as soon believe that a sheep was a plant. Naturally piqued by this want of faith, I have thought a good deal over the matter, and as I still rest in the lame conclusion I originally expressed must even now confess that I cannot certainly say whether this creature is an animal or a plant."

Thus in the question of making proteid there are all gradations from plants able to make proteid from inorganic matter to plants which are as much animal as vegetable in structure, but are animal in the dependence on other organisms for their food. The singular circumstance observed by Meyer that the torula of yeast, tho an indubitable plant, still flourishes most vigorously when supplied with the complex nitrogenous substance pepsin, the probability that the potato blight is nourished directly by the protoplasm of the potato-plant, and the wonderful facts which have recently been brought to light respecting insectivorous plants all favor this view and tend to the conclusion that the difference between animal and plant is one of degree rather than of kind and that the problem whether, in a given case, an organism is an animal or a plant may be essentially insoluble.

This conception that animals and plants differ not in kind has been of great importance in the development of biology as a unified science of life. But, altho the differences in the organic functions are of degree rather than of kind, it is true that the differences of degree are clear enough, except in certain unicellular organisms which are on the border line, to enable us to distinguish between animals and plants and to make it convenient to divide physiology, the science of function, into plant and animal physiology. These differences will be clearer by adding to Huxley's general comparison of plants and animals a concrete comparison of an animal and a plant. For this purpose one of Huxley's most famous students, T. Jeffery Parker, chose the unicellular animal "Amoeba" and the unicellular plant

"Haematococcus," also known as "Sphaerella." Both of these live in water. In their nutrition there are some differences, for Amoeba can take in solid food (other small animals and plants), formed of protoplasm as complex as its own. These it breaks up by means of digestive juices into soluble proteids and then recombines them to form its own protoplasm. Haematococcus has not this ability to take in solid food; it never feeds in the ordinary sense of the word. Nevertheless it must take in food in some way or other or the decomposition of its protoplasm would soon bring it to an end. The water in which it lives is never pure, but always contains certain mineral salts in solution, especially nitrates, ammonia salts and often sodium chloride or common table salt. These salts, being crystalloids, can and do diffuse into the water of the organism so that we may consider its protoplasm to be constantly permeated by a very weak saline solution, the most important elements contained in which are oxygen, hydrogen, nitrogen, potassium, sodium, calcium, sulphur and phosphorus. It must be remarked, however, that the diffusion of these salts does not take place in the same uniform manner as it would through parchment or other dead membrane. The living protoplasm has the power of determining the extent to which each constituent of the solution shall be absorbed.

"If water containing a large quantity of Haematococcus is exposed to sunlight minute bubbles are found to appear in it, and these bubbles, if collected and properly tested, are found to consist largely of oxygen. Accurate chemical analysis has shown that this oxygen is produced by the decomposition of the carbon dioxide contained in solution in rain-water, and indeed in all water exposed to the air, the gas, which is always present in small quantities in the atmosphere, being very soluble in water.

"As the carbon dioxide is decomposed in this way, its oxygen being given off, it is evident that its carbon must be retained. As a matter of fact, it is retained by the organism, but not in the form of carbon. In all probability a double decomposition takes place between the carbon dioxide absorbed and the water of organization, the result being the liberation of oxygen in the form of gas and the simultaneous production of some extremely simple form of carbohydrate—*i.e.*, some compound of carbon, hydrogen and oxygen, with a comparatively small number of atoms to the molecule.

"The next step seems to be that the carbohydrate thus formed unites with the ammonia salts or the nitrates absorbed from the surrounding water, the result being the formation of some comparatively simple nitrogenous compound. Then further combinations take place, substances of greater and greater complexity are produced. sulphur from the absorbed sulphates enters into combination and proteids are formed. From these finally fresh living protoplasm arises.

"From the foregoing account, which only aims at giving the very briefest outline of a subject as yet imperfectly understood, it will be seen that, as in Amoeba, the final result of the nutritive process is the manufacture of protoplasm, and that this result is attained by the formation of various substances of increasing complexity. But it must be noted that the steps in the process of constructive metabolism are widely different in the two cases. In Amoeba we start with living protoplasm—that of the prey which is killed and broken up into diffusible proteids, these being afterward recombined to form new molecules of the living protoplasm of Amoeba. So that the food of Amoeba is, to begin with, as complex as itself, and is broken down by digestion into simpler compounds, these being afterward recombined into more complex ones. In Haematococcus, on the other hand, we start with extremely simple compounds, such as carbon dioxide, water, nitrates, sulphates, etc. Nothing which can be properly called digestion—*i.e.*, a breaking up and dissolving of the food, takes place, but its various constituents are combined into substances of gradually increasing complexity, protoplasm, as before, being the final result.

"To express the matter in another way: Amoeba can only make protoplasm out of proteids already formed by some other organism; Haematococcus can form it out of simple liquid and gaseous inorganic materials.

"Speaking generally, it may be said that these two methods of nutrition are respectively characteristic of the two great groups of living things. Animals require solid food containing ready-made proteids and cannot build up their protoplasm out of simpler compounds. Green plants—*i.e.*, all the ordinary trees, shrubs, weeds, etc.—take only liquid and gaseous food and build up their protoplasm out of carbon dioxide, water and mineral salts. The first of these methods of nutrition is conveniently distinguished as holozoic, or wholly-animal, the second as holophytic, or wholly-vegetal.

"It is important to note that only those plants or parts of plants in which chlorophyll is present are capable of holophytic nutrition. Whatever may be the precise way in which the process is effected, it is certain that the decomposition of carbon dioxide which characterizes this form of nutrition is a function of chlorophyll, or to speak more accurately, of chromatophores, since there is reason for thinking that it is the protoplasm of these bodies, and not the actual green pigment, which is the active agent in the process.

"Moreover, it must not be forgotten that the decomposition of carbon dioxide is carried on only during daylight, so that organisms in which holophytic nutrition obtains are dependent upon the sun for their very existence. While Amoeba derives its energy from the breaking down of the proteids in its food, the food of Haematococcus is too simple to serve as a source of energy, and it is only by the help of sunlight that the work of constructive metabolism can be carried on. This may be expressed by saying that Haematococcus, in common with other organisms containing chlorophyll, is supplied with kinetic energy (in the form of light or radiant energy) directly by the sun.

"As in Amoeba, destructive metabolism is constantly going on, side by side with constructive. The protoplasm becomes oxidized, water, carbon dioxide and nitrogenous waste matters being formed and finally got rid of. Obviously then absorption of oxygen must take place, or in other words, respiration must be one of the functions of the protoplasm of Haematococcus as of that of Amoeba. In many green—*i.e.*, chlorophyll containing—plants this has been proved to be the case; respiration—*i.e.*, the taking in of oxygen and giving out of carbon dioxide—is constantly going on, but during daylight is obscured by the converse process, the taking in of carbon dioxide for nutritive purposes and the giving out of the oxygen liberated by its decomposition. In darkness, when this latter process is in abeyance, the occurrence of respiration is more readily ascertained."

CHAPTER VIII

LIFE PROCESSES

NUTRITION thus, as has been pointed out, makes it possible to classify most organisms as animals or plants. Yet there are many unicellular forms in which both kinds of nutrition go on at the same time; that is, the forms may possess a mouth for the ingestion of solid food and green coloring matter, chlorophyll, for the manufacture of starchy food from gaseous matter.

Many of the lowest forms of life have long been puzzles and the beginner in biological study is surprised to find them described in text books of both botany and zoology. The fact is that they are on the border line, are neither plants nor animals but simply organisms. Since they cannot be classified, it is necessary that they be listed both under botany and zoology, in order to make sure that they will not be omitted entirely. Because of these uncertain forms of life, Haeckel proposed once to include all one-celled animals and plants in a third kingdom to be called Protista (meaning the first of all life).

Parker's definition of animals and plants, based on the foregoing considerations, is convenient for distinguishing between animals and plants in all cases except the doubtful unicellar forms. He says:

"Animals are organisms of fixed and definite form, in which the cell-body is not covered with a cellulose wall. They ingest solid proteinaceous food, their nutritive processes result in oxidation, they have a definite organ of excretion and are capable of automatic movement.

"Plants are organisms of constantly varying form in which the cell-body is surrounded by a cellulose wall; they cannot ingest solid food, but are nourished by a watery solution of nutrient materials. If chlorophyll is present, the carbon dioxide of the air serves as a source of carbon, nitrogen is obtained from simple salts and the nutritive processes result in deoxidation; if chlorophyll is absent, carbon is obtained from sugar or some similar compound, nitrogen either from simple salts or from proteids, and the process of nutrition is one of oxidation. There is no special excretory organ, and, except in the case of certain reproductive bodies, there is usually no locomotion."

The important point to recognize is that these boundaries are artificial and that there are no scientific frontiers in Nature. As in the liquefaction of gases, there is a "critical point" at which the substance under experiment is neither gaseous nor liquid; as in a mountainous country, it is impossible to say where mountain ends and valley begins; as in the development of an animal, it is futile to argue about the exact period when, for instance, the egg becomes a tadpole or the tadpole a frog, so in the case under discussion. The distinction between the higher plants and animals is perfectly sharp and obvious, but when the two groups are traced downward they are found gradually to merge, as it were, into an assemblage of organisms which partake of the characters of both kingdoms and cannot without a certain violence be either included in or excluded from either. When any given "protist" has to be classified the case must be decided on its individual merits; the organism must be compared in detail with all those which resemble it closely in structure, physiology and life history, and then a balance must be struck and the doubtful form placed in the kingdom with which it has, on the whole, most points in common.

It will no doubt occur to the reader that, on the theory of evolution, the fact of the animal and vegetable kingdoms being related to one another like two trees united at the roots may be accounted for by the hypothesis that the earliest organisms were protists and that from them animals and plants were evolved along divergent lines of descent. And in this connection the fact that some bacteria—the simplest organisms known and devoid of chlorophyll—may flourish in solutions wholly devoid of organic matter is very significant.

The lower plants and animals referred to above are so far from everyday observation and hence so unfamiliar that to most people the comparison made will mean little in terms of ordinary green flowering plants and common vertebrate animals. In order to emphasize the fundamental similarity of organic function in higher and lower animals and plants, let us compare any higher plant—*e.g.,* a bean plant with a higher animal, *e.g.,* frog or even man. In each the life is the sum total of a series of definite processes—nutrition or food supply, circulation, metabolism, excretion, oxygenation (part of respiration), movement, irritability (nervous activity) and reproduction. In turn these will be compared for the animal and the plant, following in part the comparisons of certain animals and plants by Sedgwick and Wilson and others. These comparisons will, however, be translated into terms applicable to any species of higher plants or animals.

In the nutrition of the animal the most essential and characteristic part of the food supply is derived from vegetable or animal matter in the form of various organic compounds, of which the most important are proteids (protoplasm, albumen, etc.), carbohydrates (starch, cellulose) and fats. These materials are used by the animal in the manufacture of new protoplasm to take the place of that which has been used up. It is however, impossible for the animal to build these materials directly into the substance of its own body. They must first undergo certain preparatory chemical changes known collectively as digestion, and only after the completion of this process can all the food be absorbed into the circulation.

For this purpose the food is taken not into the body proper, but into a kind of tubular chemical laboratory called the alimentary canal, through which it slowly passes, being subjected meanwhile to the action of certain chemical substances or reagents, known as digestive ferments. These substances, which are dissolved in a watery liquid to form the digestive fluid, are secreted by the walls of the alimentary tube. Through their action the solid portions are liquefied and the food is rendered capable of absorption into the body proper.

The food supply of the higher plant, like that of the animal, is the source of the required matter and energy, but unlike that of the animal, it is not chiefly an income of foods, but only of the raw materials of food. Matter enters the plant in the liquid or gaseous form by diffusion, both from the soil through the roots (liquids) and from the atmosphere through the leaves (gases). We have here the direct absorption into the body proper of food-stuffs precisely as the animal takes in water and oxygen. Energy enters the plant, to a small extent, as the potential energy of food-stuffs, but comes in principally as the kinetic energy of sunlight absorbed in the leaves.

Of the substances the solids (salts, etc.) must be dissolved in water before they can be taken in. Water and dissolved salts continually pass by diffusion from the soil into the roots, where together they constitute the sap. The sap travels throughout the whole plant, the main tho not the only cause of movement being the constant transpiration (evaporation) of watery vapor from the leaves, especially through the stomata. The gaseous matters (carbon dioxide, oxygen, nitrogen) enter the plant mainly by diffusion from the atmosphere, are dissolved by the sap in the leaves and elsewhere and thus may pass to every portion of the plant.

The green plant owes its power of absorbing the energy of sunlight to the chlorophyll-bodies or chromatophores, for plants which, like fungi, etc., are devoid of chlorophyll, are unable thus to acquire energy. Entering the chlorophyll-bodies, the kinetic energy of sunlight is applied to the decomposition of carbon dioxide and water. After passing through manifold but imperfectly known processes, the elements of these substances finally reappear as starch, often in the form of granules embedded in the chlorophyll-bodies and free oxygen, most of which is returned to the atmosphere. Thus the leaf of a green plant in the light is continually absorbing carbon dioxide and giving forth free oxygen.

Carbon dioxide and water contain no potential energy, since the affinities of their constituent elements are completely satisfied. Starch, however, contains potential energy, since the molecule is relatively unstable—*i.e.*, capable of decomposition into simpler, stabler molecules in which stronger affinities are satisfied. And this is due to the fact that in the manufacture of starch in the chlorophyll-bodies the kinetic energy of sunlight was expended in lifting the atoms into position of vantage, thus endowing them with energy of position. In this way some of the radiant and kinetic energy of the sun comes to be stored up as potential energy in the starch. In short, the green plant is able by coöperation with sunlight to use simple raw materials (carbon dioxide, water, oxygen, etc.) poor in energy or devoid of it, and out of them to manufacture food—*i.e.*, complex compounds rich in available potential energy. This power is possessed by green plants alone; all other organisms being dependent for energy upon the potential energy for ready-made food. This must, in the first instance, be provided for them by green plants, and hence without chlorophyll-bearing plants, animals (and colorless plants as well)apparently could not long exist.

The plant absorbs also a small amount of kinetic energy, independently of the sunlight, in the form of heat. This, however, is probably not a source of vital energy, but only contributes to the maintenance of the body temperature.

Food (starch) thus produced in the green leaves of higher plants and the inorganic foods (water, nitrites or nitrates and various mineral substances in solution in water) furnish the materials and energy required for the life and growth of the plant.

The circulatory system distributes these foods. In animals foods prepared for absorption in the stomach and intestine (by digestion) are absorbed by the circulating liquids (blood and lymph) and transported to all cells of the animal body. In the plant the inorganic matter in water from the soil is absorbed by the roots and carried up definite tubes in the woody part of the stem. The causes of this ascent are not clear, but root-pressure due to osmosis, capillary action and evaporation from the leaves are factors. Just as the solid food of animals must be digested in preparation for absorption, so starch manufactured in the leaves must be digested (dissolved) before it can be transported. This is done by diastase, an enzyme of plant cells. The change is from starch to a sugar capable of diffusion. Dissolved in water, the sugar is transported down delicate tubes, chiefly in the growing bark region of the stem. It is clear that there are upward and downward currents of water containing food (comparable to blood of an animal), but no system of complete circulation as in the blood vessels of a higher animal. However, the result in distributed food is the same in the plant and in the animal.

In the cells the foods undergo metabolic changes. In an animal the foods in the circulating liquids, blood and lymph, are selected and absorbed by the cells. Only proteid foods form new protoplasm and even of proteids only a limited amount, seventy-five to one hundred grams a day for a man, is built into new protoplasm. The excess undergoes oxidation and forms nitrogen excretions. The foods containing only the elements carbon, hydrogen and oxygen (fats and carbohydrates) are directly oxidized to excretions and, lacking nitrogen, cannot serve for making new animal protoplasm. Fat and carbohydrate foods, then, never become living matter. They may be stored, especially as fat, until needed for oxidation to supply energy. The building up of the protoplasm from proteids is anabolism, constructive metabolism. The destruction of protoplasm, excess proteids or the fat and carbohydrate foods is katabolism, destructive metabolism. Katabolism is probably due to enzyme action, but the final result is chiefly carbon dioxide and water, which could be derived by the ordinary chemical evolution of protoplasm, proteid, sugar, starch or fats.

In the plant, starch, as has been seen, is first formed in the chlorophyll-bodies. But the formation of starch, all-important as it is, is after all only the manufacture of food as a preliminary to the real processes of nutrition. These proceses must take place everywhere in ordinary protoplasm, for it is here that oxidation occurs and the need for a renewal of matter and energy consequently arises. Sooner or later the starch grains are changed into a kind of sugar (glucose), which, unlike starch, dissolves in the sap and may thus be easily transported to all parts of the plant. Wherever there is need for new protoplasm, whether to repair previous waste or to supply materials for growth, after absorption into the cells the elements of the starch (or glucose) are, by the living protoplasm, in some unknown way combined with nitrogen and sulphur (probably also with salts, water, etc.) to form proteid matter. The particles of this newly formed compound are incorporated into the protoplasm.

If a larger quantity of starch is formed in the chlorophyll-bodies than is immediately needed by the protoplasm for purposes of repair or growth, it may be reconverted into starch after journeying as glucose through the plant and be laid down as "reserve starch" in the cells of root or stem or elsewhere. Apparently when this reserve supply is finally needed at any point in the plant, it is again changed to glucose and transported thither. It is probable that new leaves and new tissues generally are always formed in part from this reserve starch.

In the plant as in the animal metabolism must consist of anabolic and katabolic processes. The construction in the cells of new proteid from the absorbed carbohydrate and the materials from the soil is true anabolism. It is also clear that katabolism or oxidation for the liberation of energy occurs as in animals, but this process is slower. Probably foods containing carbon, hydrogen and oxygen are the sources of energy in the higher plants as in animals.

In both plants and animals simple waste substances result from the katabolic processes in the cells. In the animal carbon dioxide, water and nitrogen compounds are the chief excretions. They are absorbed by the circulating liquids and carried to the eliminating organs, lungs and kidneys chiefly, for elimination. In the higher plants the excretions are carbon dioxide, which escapes through the epidermis of root, stem and leaf and through the stomata; water which is lost by evaporation, especially from the leaf surface through the stomata; excretions which are lost by osmosis through the roots and the accumulated but useless mineral substances which are eliminated by leaf fall.

In both animals and plants oxygen is essential to the katabolic part of metabolism. Hence oxygen must be supplied to the cells. Oxygenation is the term used to denote the oxygen-supplying part of respiration, elimination of carbon dioxide, has been treated under excretions. In the animal oxygen is absorbed by the blood, in excess by the hemoglobin of the red cells of the blood and later is absorbed from the blood and lymph by all the living cells. In the plant also oxygen is absorbed through the epidermis and stomata from the air. This process is, however, obscured during the day because of the oxygen freed in the manufacture of starch which goes on at that time. Probably this freed oxygen is used for the purpose of oxygenation, but more is freed in the photosynthetic process than is needed for oxygenation and hence the excess oxygen is eliminated while starch manufacture is in process.

In comparing a higher animal and a green plant confusion must be avoided regarding the part played by oxygen and carbon dioxide in true respiration with the part played by the same substances in starch formation (photosynthesis). In non-green plants like the Indian pipe and mushrooms the breathing of oxygen and the excretion of carbon dioxide are as in the animal. This is true also of green plants in darkness and even in the light of all parts of green plants except the chlorophyll-bodies. These constitute a sort of extra mechanism, enabling green plants to make their own carbohydrate food. Imagine a higher animal with an attachment for turning the carbon dioxide and water excreted back to starch usable as food and the comparison of the green plant and the animal would be complete.

The power of movement or locomotion is curiously thought of as peculiar to animals, but biologists know dozens of examples of movement in plants. Some of the lower plants possess the power of locomotion and even in plants as high as mosses and ferns there is a locomotion of the male germ-cells. Among the flowering plants there is no actual locomotion, but there are numerous forms of movement. Most striking perhaps are the so-called "sleep-movements" of plants by means of which the leaves of some plants—*e.g.*, the oxalis, bean, clover, locust and others—can assume decidedly different positions at night from those which they occupy by day; the movements of the sensitive plant

(Mimosa) when "shocked" by touch or in other ways, and the movements of the leaves of the Venus flytrap (Dionea), which close with a quick jerk when the sensitive hairs with which they are bordered are stimulated.

It is in nervous functions that the most striking difference between the animal and the plant is to be found. Plants have no true nervous system, nevertheless irritability or response to stimulus is well marked in many plants. It would carry us far beyond the limits of this volume to trace satisfactorily the powers of plants to respond to stimuli of gravity, light, heat, water, electricity, chemicals, contact, injury and so on. Suffice it to say that the total effect of such responses is for the plant equal to that of the nervous system for the animal.

Reproduction is a most important function. The life of every organic species runs in regularly recurring cycles, for every individual life has its limit. In youth the constructive processes preponderate over the destructive and the organism grows. The normal adult attains a state of apparent physiological balance in which the processes of waste and repair are approximately equal. Sooner or later, however, this balance is disturbed. Even tho the organism escapes every injury or special disease, the constructive process falls behind the destructive, old age ensues and the individual dies from sheer inability to live. Why the vital machine should thus wear out is a mystery, but that it has a definite cause and meaning is indicated by the familiar fact that the span of natural life varies with the species; man lives longer than the dog, the elephant longer than man.

It is a wonderful fact that living things have the power to detach from themselves portions or fragments of their own bodies endowed with fresh powers of growth and development and capable of running through the same cycle as the parent. There is therefore an unbroken material (protoplasmic) continuity from one generation to another that forms the physical basis of inheritance and upon which the integrity of the species depends. As far as known, living things never arise save through this process. In other words, every mass of existing protoplasm is the last link in an unbroken chain that extends backward in the past to the first origin of life.

The detached portions of the parent that are to give rise to offspring are sometimes masses of cells, as in the separation of branches or buds among plants, but more commonly they are single cells, known as germ-cells, like the eggs of animals and the spores of ferns and mosses. Only the germ-cells (which may conveniently be distinguished from those forming the rest of the body or the somatic cells) escape death, and that only under certain conditions.

All forms of reproduction fall under one or the other of two heads, viz., agamogenesis (asexual reproduction) or gamogenesis (sexual reproduction). In the former case the detached portion (which may be either a single cell or a group of cells) has the power to develop into a new individual without the influence of other living matter. In the latter, the detached portion, in this case always a single cell (ovum, oösphere, etc.), is acted upon by a second portion of living matter, likewise a single cell, which in most cases has been detached from the body of another individual. The germ is called the female germ-cell, the cell acting upon it the male germ-cell, and in the sexual process the two fuse together (fertilization, impregnation) to form a single new cell endowed with the power of developing into a new individual. In some organisms (*e.g.* the yeast-plant and bacteria) only agamogenesis has been observed; in others (*e.g.*, vertebrates) only gamogenesis; in others still both processes take place as in many higher plants.

The earthworm, for example, is not known to multiply by a natural process of agamogenesis. It possesses in a high degree, however, the closely related power of regeneration, for if a worm be cut transversely into two pieces the anterior piece will usually make good or regenerate the missing portion, while the posterior piece may regenerate the anterior region. Thus the worm can to a certain limited extent be artificially propagated, like a plant, by cuttings, a process closely related to true agamogenesis. Its usual and normal mode of reproduction is by gamogenesis; that is, by the formation of male germ-cells (spermatozoa) and the female germ-cells (ova). In higher animals the two kinds of germ-cells are produced by different individuals of opposite sex. The earthworm, on the contrary, is hermaphrodite or bisexual; every individual is both male and female, producing both eggs and spermatozoa.

As in the animal so in the plant, whether the individual dies or not, ample provision against the death of the race is made in the act of reproduction. Although reproduction appears to be useless to the individual and even entails upon it serious annual losses of matter and energy, yet to this function every part of the plant directly or indirectly contributes. The reproductive germs are carefully prepared, are provided with a stock of food sufficient for the earliest stages of development, and are endowed with the peculiar powers and limitations of each species which influence their life history at every step and are by them transmitted in turn to their descendants. They are living portions of the parent detached for reproductive purposes and they contain a share of protoplasm directly descended from the original protoplasm from which the parent came. In short, reproduction is the supreme function of the plant.

As in the animal, reproduction in the higher plants is by the process of gamogenesis. Male germ-cells and female germ-cells are formed in separate organs. In many of the higher plants these organs are both found in the same individual, but often they are produced by different individuals of opposite sex. Agamogenesis, or asexual reproduction, also takes place in many higher plants by means of runners, buds, bulbs, tubers, etc., but in most of these cases provision is made for sexual reproduction also.

In relation to the environment animals and plants are masses of living matter occupying definite positions in space and time and existing amid certain definite and characteristic physical surroundings which constitute their "environment." As ordinarily understood the term environment applies only to the immediate surroundings of the animal and plant. Strictly speaking, however, the environment includes everything that may in any manner act upon the organisms—that is, the whole universe outside them. For they are directly and profoundly affected by rays of light and heat that travel to them from the sun; they are extremely sensitive to the alternations of day and night and the seasons of the year; they are acted on by gravity; and to all these, as well as to more immediate influence, they make definite responses.

The body of the animal is a complicated piece of mechanism constructed to perform certain definite actions. But every one of these actions is in one way or another dependent upon the environment and directly or indirectly relates to it. At every moment of its existence the organism is acted on by its environment; at every moment it reacts upon the environment, maintaining with it a constantly shifting state of equilibrium which finally gives way only when the life of the animal draws to a close.

The action of the environment upon the animal has been sufficiently stated. It remains to point out the changes worked by the animal on the environment. These changes are of two kinds, mechanical (or physical) and chemical. The general effect of the metabolism of the animal is the destruction by oxidation of organic matter; that is, matter originally taken from the environment in the form of complex proteids, fats, and carbohydrates is returned to it in the form of simpler and more highly oxidized substances, of which the most important are carbon dioxide and water (both inorganic substances). This action furthermore is accompanied by a dissipation of energy—that is, a conversion of potential into kinetic energy.

On the whole, therefore, the action of the animal upon the environment is that of an oxidizing agent, a reducer of complex compounds to simpler ones, and a dissipator of energy.

The actions of the environment upon the plant have been sufficiently dwelt upon. It still remains, however, to consider the actions of the plant upon the environment. These are partly physical, but mainly chemical. By pushing its stems and leaves into the air and slowly thrusting its roots through the soil, the atmosphere and the earth are alike displaced. But it is by its chemical activity that it most profoundly affects its environment. Absorbing from the latter water, salts, carbon dioxide, and other simple substances, as well as sunlight, it produces with them a remarkable metamorphosis. It manufactures from them as raw materials organic matter in the shape of starch, fats, and even proteids. These it gives back to the environment in some measure during life, and surrenders wholly after sudden death. But the most striking fact is that the plant is on the whole constructive and capable of producing and accumulating compounds rich in energy and in this respect it is unlike the animal.

Thus, while animals are destroyers of energized compounds, green plants are producers of them. Animals, therefore, in the long run, are absolutely dependent on plants; and animals and colorless plants alike upon green plants. But it must never be forgotten that most plants are enabled to manufacture organic from inorganic matter by virtue of the chlorophyll which they contain. Without this they are powerless in this respect.

It is evident that to the superficial observer the plant and animal seem to have little or nothing in common, except that both are what we call alive. But whoever has studied the preceding pages must have perceived beneath manifold differences of detail a fundamental likeness between the plant and animal, not only in the substantial identity of the living matter in the two but also in the construction of their bodies and in the processes by which they come into existence. "Each arises from a single cell," to quote Sedgwick and Wilson, "which is the result of the union of two differently constituted cells, male and female. In both the primary cell multiplies and forms a mass of cells, at first nearly similar but afterward differentiated in various directions to enable them to perform different functions—*i.e.*, to effect a physiological division of labor. In both, the tissues thus provided are associated more or less closely into distinct organs and systems, among which the various operations of the body are distributed. And in both the ultimate goal of individual existence is the production of germ-cells which form the starting-point of new and similar cycles.

"This fundamental likeness extends also to most of the actions (physiology) of the two organisms. Both possess the power of adapting themselves to the environments in which they live. Both take in various forms of matter and energy from the environment, build them up into their own living substance, and finally break down this substance more or less completely into simpler compounds by processes of internal combustion, setting free by this action the energy which maintains the vital activity. And, sooner or later, both give back to the environment the matter and energy which they have taken from it. In other words, both effect an exchange of matter and of energy with the environment."

Nevertheless the plant and the animal differ. They differ widely in form, and the plant is fixed and relatively rigid, while the animal is flexible and mobile. The body of the plant is relatively solid; that of the animal contains numerous cavities. The plant absorbs matter directly through the external surface; the animal partly through the external and partly through an internal (alimentary) surface. The plant is able to absorb simple chemical compounds from the air and earth, and kinetic energy from sunlight; the animal absorbs, for the most part, complex chemical compounds and makes no nutritive use of the sun's kinetic energy. By the aid of this energy the plant manufactures starch from simple compounds, carbon dioxide and water; the animal lacks this power. The plant can build up proteid from the nitrogeneous and other compounds of its food. And by manufacturing proteids within its living substance, the plant is relieved of the necessity of carrying on a process of digestion in order to render them diffusible for entrance into the body.

Still, great as these differences appear to be at first sight, all of them, with a single exception, fade away upon closer examination. This exception is the power of making foods. Plants and animals differ in form because their mode of life differs; but a wider study of biology reveals the existence of innumerable animals (corals, sponges, hydroids, etc.) which have a close superficial resemblance to plants, and of many plants which resemble animals, not only in form, but also in possessing the power of active locomotion. The stomach of the animal, as shown by its development, is really a part of the general outer surface which is folded by the body; and the animal, like the plant, therefore, really absorbs its income over its whole surface—oxygen through the general outer surface, other food-matters through the infolded alimentary surface.

In like manner it is easy to show that not one of the differences between the plant and animal is fundamentally important save the power of making foods. The animal must have complex ready-made food, including proteid matter. So must the plant; but the plant is able to manufacture this complex food out of very simple compounds. In terms of energy, the animal requires ready-made food rich in potential energy; the plant, aided by the sun's energy, can manufacture food from matters devoid of energy. Hence it appears, broadly speaking, that the plant by the aid of solar energy is constructive, and stores up energy; the animal is destructive, and dissipates energy. And this difference becomes of immense importance in view of the fact that it is true in this respect of all green plants, as of all animals.

Even this difference, great as it is, is partly bridged over by colorless plants like yeast, molds, bacteria, etc., which have no chlorophyll, are therefore unable to use the energy of life, and hence must have energized food. But these organisms do not, like animals, require proteid food, being able to extract all needful energy from the simpler fats, carbohydrates, and even from certain salts. When it is considered that the distinctive peculiarities of animals can thus be reduced to the sole characteristic of dependence on proteid food, it cannot be doubted that the difference between plants and animals is of immeasurably less importance than their fundamental likeness, the more so when it is kept in mind that each of the principles of organic functions will be found to apply to all animals including man himself and to all plants, however complex they may be.

CHAPTER IX

ORIGIN OF SPECIES OF PLANTS AND ANIMALS

THERE are in the museums of the world at the present time representatives of several hundred thousand—probably more than a million—kinds or species of plants and animals, and thousands of new species are being discovered and named each year. A single group of insects has classified under it more species than there are stars to be seen in the heavens with the unaided eye on a clear night. Aristotle knew about five hundred kinds of animals, but a single new botanical or zoological work may now describe more than that number of species new to the records of Science. Linnaeus in 1758 published the tenth edition of his "Systema Naturae" and named about four thousand animals, and every year since 1864 the "Zoological Record" has listed three or four times this number of species previously undescribed, yet now, as in Linnaeus's time, it is certain that not half of the number of species of animal organisms is yet known. The six hundred thousand, more or less, on the registers of Science to-day are certainly far less than half of the millions which actually exist.

In botany the same conditions are to be found. There are fewer known species of plants than animals by half, and they are more easily preserved and handled, while the work of collection and investigation proceeds on a scale even more extensive, yet it would be a bold statement to say that to-day half the species of plants that exist are known.

All this refers to the forms now living, without reference to the host which composes their long ancestry, extending backward toward the dawn of creation. The species have come down through the geological ages, changing in form and function to meet the varying needs of changing environment. This enumeration takes no account of the still vaster myriads of forms almost endlessly varied, which have perished utterly in the pressure of environment, leaving no trace in the line of descent.

It is evident that variety in life is a factor in the history of the globe, that it may be expressed in terms of number of species, but that the actual range of variation is far greater than the number of species, and that if causes are to be judged by range of effects, in the origin of species must be found the operation of world-wide forces, the cooperation of great influences, far-reaching in time and space, as broad as the surface of the globe and as enduring as its life.

The cause of this amazing variety in life, and the manner of accounting for origin of species are questions necessarily asked when attention is called to the existence of such vast numbers of species of plants and animals. In earlier chapters the theories of the origin of life have been described and proof that present living matter has descended from preëxisting living matter has been outlined. It is, in fact, accepted in modern science that there has been a continuity of descent from the first living matter to that of the present time. But the form or species in which life first originated is another subject, and almost as great. Such a subject must deal with the questions as to whether life first appeared in each species of animal or plant separately, or whether it began in simple protoplasm from which have been evolved the almost numberless species known to-day.

It is quite clear that there are only two hypotheses in the field whereby it is possible so much as to suggest an explanation of the origin of species. Either all the species of plants and animals must have been supernaturally created, or else they must have been naturally evolved. There is no third hypothesis possible; for no one can rationally suggest that species have been eternal.

It should be noticed that whichever of the two rival theories is entertained, the concern is not with any question touching the origin of life, but only with the origin of particular forms of life—that is to say, with the origin of species. The theory of descent starts from life as a "datum" already granted. How life itself came to be, the theory of descent, as such, is not concerned to show. Therefore, in the present discussion, the existence of life is taken as a fact which does not fall within its range of debate.

The history of biology in the nineteenth century will be famous because of the discussion of these two hypotheses which attempt to account for the existence of the innumerable species of living things which inhabit the earth: the theory of creation and the theory of evolution. According to the theory of creation, all the individuals of every species existing at the present day—the tens of thousands of dogs, oak trees, amoebae, and what-not—are derived by a natural process of descent from a single individual, or from a pair of individuals—in each case precisely resembling, in all essential respects, their existing descendants—which came into existence by a process outside the ordinary course of nature, and known as Creation.

According to the rival theory—that of Descent or Organic Evolution—every species existing at the present day is derived by a natural process of descent from some other species which lived in a former period of the world's history. If from generation to generation the individuals of any existing species could be traced back, on this hypothesis, their characters would be found gradually to change, until finally a period was reached at which the differences were so considerable as to necessitate the placing of the ancestral forms in a different species from their descendants at the present day. And in the same way if the species of any one genus could be traced back they would gradually approach one another in structure until they finally converged in a single species, differing from those now existing but standing to all in a true parental relation.

In regard to the present standing of these two theories it should be stated that the theory of descent is now generally accepted by men of science and the theory of special creation rejected. In fact no great naturalist since Agassiz has attacked the general theory, tho some have debated many of its minor details. As David Starr Jordan has said: "There is to-day no doubt in our minds of the truth, the actuality, of descent. It is not the theory of descent: it is the fact, the law, of descent, of which we talk and write. Organisms are blood-related; they are transformed, descended from one another."

At this point it will clarify some later considerations if it is emphasized that there is a great distinction to be drawn between the fact of evolution and the manner of it, or between the evidence of evolution as having taken place somehow, and the evidence of the causes which have been concerned in the process. This most important distinction is frequently disregarded by popular writers on evolution, and, therefore, in order to mark it as strongly as possible, it will be necessary to effect a complete separation between the evidence of evolution as a fact, and the evidence as to its method. In other words, not until the evidence of organic evolution as a process, which somehow or another has taken place, has been fully considered, is it advisable to consider how it has taken place, or the cause which Darwin and others have suggested as having probably been concerned in this process.

First there is to be considered, therefore, the evidences pointing to the fact of organic descent (evolution) of species of animals and plants and later there will be outlined the trend of the enormous amount of investigation which has been and now more actively than ever is being done toward the solution of the problems concerned with the causes or the factors of evolution. In passing, it must be noted that while Darwin wrote both concerning the evidences of evolution and the manner or causes of evolution, it is not correct, as many authors assume, to regard the "Darwinian Theory" or "Darwinism" as synonymous with the theory of descent or evolution. Rather should the terms "Darwinism" and "Darwinian Theory" be applied to the theory of natural selection, Darwin's great explanation of the cause of the origin of species by evolution or descent.

The late Professor Cope, of Philadelphia, defines evolution in the broadest sense, including both organic and inorganic evolution, as follows: "The doctrine of evolution may be defined as the teaching which holds that creation has been and is accomplished by the agency of the energies which are intrinsic in the evolving matter, and without the interference of agencies which are external to it. It holds this to be true of the combinations and forms of inorganic nature, and of those of organic nature as well. Whether the intrinsic energies which accomplish evolution be forms of radiant or other energy only, acting inversely as the square of the distance, and without consciousness, or whether they be energies whose direction is affected by the presence of consciousness, the energy is a property of the physical basis of tridimensional matter, and is not outside of it."

But a distinction must be made between organic and inorganic evolution. Professors Jordan and Kellogg have stated this most clearly in "Evolution and Animal Life": "Biological evolution and cosmic evolution are not the same. From the biological side a certain objection must be made to this philosophical theory of universal or cosmic evolution. In organic and inorganic evolution there is much in common, so far as conditions and results are concerned; but these likenesses belong to the realm of analogy, not of homology. They are not true identities because not arising from like causes. The evolution of the face of the earth forces parallel changes in organic life, but the causes of change in the two cases are in no respect the same. The forces or processes by which mountains are built or continents established have no homology with the forces or processes which transformed the progeny of reptiles into mammals or birds.

"Tendencies in organic development are not mystic purposes, but actual functions of actual organs. Tendencies in inorganic nature are due to the interrelations of mass and force, whatever may be the final meanings attached to these terms or to the terms matter and energy. It is not clear that science has been really advanced through the conception of the essential unity of organic evolution and cosmic evolution. The relatively little the two groups of processes have in common has been overemphasized as compared with their fundamental differences.

"The laws which govern living matter are in a large extent peculiar to the process of living. Processes which are functions of organs cannot exist where there are no organs. The traits of protoplasm are shown only in the presence of protoplasm. For this reason we may well separate the evolution of astronomy, the evolution of dynamic geology and of physical geography, as well as the purely hypothetical evolution of chemistry, from the observed phenomena of the evolution of life.

"To regard cosmic evolution and organic evolution as identical or as phases of one process is to obscure facts by verbiage. There are essential elements in each not shared by the other—or which are at least not identical when measured in terms of human experience. It is not clear that any force whatever or any sequence of events in the evolution of life is homologous with any force or sequence in the evolution of stars and planets. The unity of forces may be a philosophical necessity. A philosophical necessity or corner in logic is unknown to science. We can recognize no logical necessity until we are in possession of all the facts. No ultimate fact is yet known to science.

"For reasons indicated above the term 'evolution' is not wholly acceptable as the name of a branch of science. The term 'bionomics' is a better designation of the changing of organisms influenced through unchanging laws. It is a name broader and more definite than the term organic evolution, it is more euphonious than any phrase meaning life adaptation, it involves and suggests no theory as to the origin of the phenomena it describes."

The theory of descent of plants and animals is defined by the same authors as the "belief that organs and species as we know them are derived from other and often simpler forms by processes of divergence and adaptation. According to this theory all forms of life now existing, or that have existed on the earth, have risen from other forms of life which have previously lived in turn. All characters and attributes of species and groups have developed with changing conditions of life. The homologies among animals are the results of common descent. The differences are due to various influences, one of the leading forces among these being competition in the struggle for existence between individuals and between species, whereby those best adapted to their surroundings live and produce their kind."

This theory is now the central axis of all biological investigation in all its branches, from ethics to histology, from anthropology to bacteriology. In the light of this theory every peculiarity of structure, every character or quality of individual or species, has a meaning and a cause. It is the work of the investigator to find this meaning as well as to record the fact. "One of the noblest lessons left to the world by Darwin," says Frank Cramer, "is this, which to him amounted to a profound, almost religious conviction, that every fact in nature, no matter how insignificant, every stripe of color, every tint of flowers, the length of an orchid's nectary, unusual height in a plant, all the infinite variety of apparently insignificant things, is full of significance. For him it was an historical record, the revelation of a cause, the lurking place of a principle." It is therefore a fundamental principle of the science of bionomics that every structure and every function of to-day finds its meaning in some condition or in some event of the past.

Darwin's own view of the doctrine of descent is clearly set forth in the following passages from the "Origin of Species": "Authors of the highest eminence seem to be fully satisfied with the view that each species has been independently created. To my mind it accords better with what we know of the laws impressed on matter by the

Creator, that the production and extinction of the past and present inhabitants of the world should have been due to secondary causes, like those determining the birth and death of the individual.

"When I view all beings not as special creations, but as the lineal descendants of some few beings which lived long before the first bed of the Cambrian system was deposited, they seem to me to become ennobled. Judging from the past, we may safely infer that not one living species will transmit its unaltered likeness to a distant futurity. And of the species now living very few will transmit progeny of any kind to a far distant futurity; for the manner in which all organic beings are grouped, shows that the greater number of species in each genus, and all the species in many genera, have left no descendants, but have become utterly extinct. We can so far take a prophetic glance into futurity as to foretell that it will be the common and widely spread species, belonging to the larger and dominant groups within each class, which will ultimately prevail and procreate new and dominant species. As all the living forms of life are the lineal descendants of those which lived long before the Cambrian epoch, we may feel certain that the ordinary succession by generation has never once been broken, and that no cataclysm has desolated the whole world.

"It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent upon each other in so complex a manner, have all been produced by laws acting around us. There is grandeur in this view of life, with its several powers, having been originally breathed by the Creator into a few forms or into one; and that, while this planet has gone cycling on according to the fixed laws of gravity, from so simple a beginning, endless forms most beautiful and most wonderful have been and are being evolved."

What organic evolution does not mean is a topic which deserves some attention, as few truths have been more mis-stated. President Jordan has written in "Foot-Notes to Evolution" a strong statement concerning this, wherein he says: "Evolution is not a theory that 'man is a developed monkey.' The question of the immediate origin of man is not the central or overshadowing question of evolution. This question offers no special difficulties in theory, although the materials for exact knowledge are in many directions incomplete. Homologies more perfect than those connecting man with the great group of primates could not exist. These imply the blood relationship of the human race with the great host of lemurian mammals. As to this there can be no shadow of a doubt, and, as similar homologies, connect man with all members of the group of mammals, similar blood relationship must exist; and homologies less close but equally unmistakable connect all backboned animals one with another, and the lowest backboned types are closely joined to wormlike forms not usually classed as vertebrates.

"It is perfectly true that in the higher or anthropoid types the relations with man are extremely intimate; but man is by no means 'a developed ape'; nor is any such statement other than the vaporings of ignorance."

All animals show relationships with early primitive stocks, but it does not follow that these stocks have been closely related at the time of divergence. All animals progress. As man changes and diverges, race from race, so do they. The influence of effort, the influence of surroundings, the influence of the sifting process of natural selection, each acts upon them as it acts upon man.

The process of development is not progress, but better adaptation to conditions of life. As man becomes fitted for social and civic life, so does the animal become fitted for his life. The movement of monkeys is toward simianity, not humanity. The movement of cat life is toward felinity, of the dog races toward caninity. Each step in development, upward or downward, carries each type farther from the primitive stock. These steps are never retraced.

Before passing on to the more specific instances in which these steps are clearly shown, two principles must be stated, even at the cost of repetition: First, there is no such thing as an absolute "law of repetition." Science knows no such attitude as to declare that natural laws are statutes, declaring that events *must* happen in a certain way. It is merely a statement that, so far as observed, all the phenomena suggest that things *do* happen in a certain way. That they *might* happen in a totally different way to-morrow, every scientist will cheerfully admit, though he will guard the statement by suggesting that there would need to be a different set of causes to produce different effects. Many untrained scientistic readers are apt to think that there is some weird "evolutionary principle" within the living organism, which impels it onward to a higher level of organization. There may be. But this is a speculation, and science nowhere declares it to be an ascertained and determined truth.

Second, there is no such thing as a "law of progress," if by that is meant a regulation of organic affairs which provides that all life must proceed upward. Not only is there no such law, but there is a vast host of evidence to the contrary. The shores of Time are littered with the remains of species that could not proceed upward. The antediluvian monsters, or the Jurassic Saurians—it matters not which phraseology is used—are huge examples of the absence of any "law of progress." Nor is there any "law of movement." It is not true that an organic form must either advance or deteriorate. If an animal is fitted to secure its livelihood and breed posterity in certain surroundings, it may remain unchanged indefinitely if these surroundings do not change definitely. So the duck-mole of Australia and the tuatara of New Zealand have retained primitive features for millions of years.

"Clear thinkers have always rejected 'the Darwinian hypothesis' when stated in terms of the popular misconception. The line of junction is never at the top, always at the bottom. It is the lowest mammals which approach the lowest reptiles; it is the lower types of plants which approach the lower types of animals; it is the unspecialized, undifferentiated type from which branches diverge in different ways. There will be no second creation of man, except from man's own loins.

"Adaptation by divergence—for the most part of slow stages—is the movement of development. While occasional leaps or sudden changes occur in the process, they are by no means the rule. In most cases of 'saltatory evolution' the suddenness is in appearance only. When an epoch-making character is acquired, as the wings of a bird or the brain of man, the process of readjustment of other characters goes on with greatly increased rapidity.

"We do not expect to find birds arising from a 'flying-fish in the air, whose scales are disparting into feathers.' A flying-fish is no more of the nature of a bird than any other fish is. The slow operation of existing causes is the central fact of organic development, as it is of the evolution of mountains and valleys. Seasons change as the relations which produce them change. But midsummer never gives way to midwinter in an instant. Nor does the child in an instant become a man, tho in some periods of growth, epoch-marking causes may make development more rapid. Life is conservative. The law of heredity is the expression of its conservatism. Life changes slowly, but it must constantly change, and all change is, by necessity, divergence.

"That which we call progress rests simply on the survival of the better adapted, their survival being accompanied by their reproduction. Those that live repeat themselves. Progress and generation are alike the resultants of the various forces at work from generation to generation on and within a race or species. The same forces which bring progress to a group under one set of conditions will bring degradation under another. In their essence the factors which have brought about the various species of animals are no more laws of progress than is the attraction of gravitation. Cosmic order comes from gravitation. Organic order comes from the factors of heredity, variation, adaptation to environment and the rest. The much argued word 'evolution' will be far better understood if it be considered as a means of expressing an observed order in the succession of modifications which have made the living species of animals as we know them to-day."

Let no one for a minute suppose that biologists have banished Creation. They have shown that the preponderance of evidence is against the theory that a special fiat was issued for every beetle, regulating the number of spots on his back. But they have not attempted to show that the whole general plan of beetles "simply happened." Indeed, the feeling is to the contrary. An organism fresh from the mint of Creation would be too small for us to see with any microscope. It would be too simple for us to trace by any instrumentality now in our possession. It would contain but a few molecules, and a molecule in a drop of water is as small as an orange beside the sun. Such a race of creatures, spontaneously generated, without concessions to environment, would grow hoary with the centuries before it came to our notice. Its descendants would have belonged for ages to the unnumbered hosts of microbes before we should be aware of its creation.

"Evolution," says Prof. David Starr Jordan, "is not a creed or a body of doctrine to be believed on authority. There are many who take this name and have no interest in finding out what it means or in making any application of its principles to the affairs of life. For one who cares not to master its ideas there is no power in the world. Evolution is not a panacea or a medicine to be applied to social or personal ills. It is simply an expression of the teaching of common sense as to the order of changes in animal life. If its principles are mastered, a knowledge of evolution is an aid in the understanding of life, as knowledge of gravitation is essential in the building of machinery.

"There is nothing 'occult' in the science of evolution. It is not the product of philosophic meditation or of speculative philosophy. It is based on hard facts, and with hard facts it must deal. It seems to me that it is not true that 'Evolution is a new religion, the religion of the future.' There are many definitions of religion, but evolution does not fit any of them. It is no more a religion than gravitation is a prayer.

"One may imagine that some enthusiastic follower of Newton may, for the first time, have seen the majestic order of the solar system, may have felt how futile was the old notion of guiding angels, one for each planet, to hold it up in space. He may have received his first clear vision of the simple relations of the planets, each forever falling toward the sun and toward one another, each one by the same force forever preserved from collision. Such a man might have exclaimed, 'Great is gravitation; it is the new religion, the religion of the future!' Yet how far from a right understanding of both gravitation and religion would that man have been! In such a manner men who had been forced to a slavish interpretation of a theological theory of the world, when once brought to a clear insight of the noble simplicity of the theory of natural selection as a factor in determining the origin of species, may have exclaimed, 'Great is evolution; it is the new religion, the religion of the future!' If the result of that knowledge was the evoking of thoughts and aspirations which were religious, then the religious cause was in the man, not in the facts. The biologist does not consider himself an expert in religion as such, but being human, has a part in all human longings and spiritual desires. Yet no man will deny that wider knowledge means a wider life, and that all perceived truth enhances nobleness of character."

The evidences which have convinced men of science that the origin of the various species of plants and animals through descent is a fact are many and are drawn from various sources. As the days have long passed when the shape of the earth, or the behavior of the members of the solar system, was a fit subject for debate, so the days are now closed when the truth or falsity of the law of organic descent is a debatable thesis. That the earth is subspherical, that the planets revolve about the sun, and that species of organisms descend from other species are now to be considered matters incontrovertible.

Darwin wrote for a generation which had not accepted the general idea that life has existed on this planet for hundreds of thousands of years, during which the conditions of life changed greatly, necessarily altering the forms of life in correspondence with them, and he did his work so well that "descent with modification" is now universally accepted as the order of nature in the organic world.

CHAPTER X

THE KINSHIP OF ALL LIFE

The facts of biology which admit of adequate explanation only in connection with the theory of descent are grouped under the heads of morphology, embryology, classification, paleontology, distribution and domestication. In all these lines the facts are drawn together by a strong thread of unity. Biology traces kinships in all forms of life. There are numberless similarities and correlations and surprising uniformities. The great variety of life as exhibited in the countless species of plants and animals has been referred to, and yet, great as this variety is, there are, after all, only a few types of structure among all animals and plants, some three or four or eight or ten general modes of development. The rest are merely modifications.

It is, moreover, true that all living forms are but series of modifications and extensions of one single plan of structure. All have the same ultimate substance—the mysterious semi-fluid network of protoplasm, which is, so far as is known, the physical basis of all life; and the equally mysterious nuclear substance or chromatin which in some fashion presides over all the movements of the protoplasm and is the physical basis of the phenomena of heredity. The same laws of heredity, variability and of response to outside stimulus hold in all parts of the organic world. All organisms have the same need of reproduction. All are forced to make concession after concession to their surroundings, and in these concessions all progress in life consists. And at last each organism or each alliance of organisms must come to the greatest concession of all, which is called death. The unity in life, then, is not less a fact than is life's great diversity. Whatever emphasis is laid upon the diversity of life, the essential unity of all organisms must not be forgotten.

An examination of the facts in each of the lines of evidence makes it clear that the only reasonable explanation for the existence of a fundamental unity in organic life is the theory of descent—*i.e.*, that similarities are due to blood relationship and that differences come from adaptive modifications. The facts adduced from morphology, being the result of researches into the structure of adult animals and plans, lead to a preview of certain principles of adaptation, necessary for their interpretation.

First, it must be noted that some structures are not nonadaptive, that is, do not change to fit changed habits or conditions of life. Such structures or organs are most often found internally. For illustration: a change in the locomotive habit of a bird from that of flying to that of an ostrich is associated with an adaptive modification of locomotor structures, legs and wings, but not in any striking way is their change in the internal organs. Internal organs may persist unchanged and hence they offer good guides to classification. On the other hand, external structures are likely to undergo adaptation when habits or conditions of life change. Hence, as Jordan has said, "the inside of an animal tells the real history of its ancestry; the outside tells us only where its ancestors have been."

In the second place, it must be noted that adaptations to similar conditions may result in superficial resemblances. For example, there is a superficial resemblance between the wing of an insect and the wing of a bird—both adaptations to an aerial environment; between the heart of an insect and the heart of a vertebrate animal—both adaptations for pumping blood; between the fin of a fish and the paddles of a whale—both adaptive swimming organs, yet the resemblance in these cases does not go deeper than the surface—it is one of function only. All such cases of resemblance in function but not in detailed plan of structure are called "analogies," and mean nothing more than similarity of environment. Turning to more fundamental resemblances, such as the wing of a bat and the wing of a bird, careful study shows detailed internal as well as external similarities of structure. Such cases are "homologies."

On the one hand, then, are found structures which are perfectly analogous and yet in no way homologous: totally different structures are modified to perform the same functions. On the other hand are found structures which are perfectly homologous yet in no way analogous: the structural elements remain, but are profoundly modified to perform totally different functions. Homology thus means identity of structure which is the result of identity of parentage. It is the stamp of heredity. It means blood relationship. These principles of homology are essential to a correct interpretation of the facts of morphology.

The most striking fact of similar structure among plants and among animals is the existance of a common general plan in any group. Since backboned animals are best known to most readers, they may be taken as an illustration. "All vertebrate animals, and none other," says Le Conte, "have an internal jointed skeleton worked by muscles on the outside. The relation of skeleton and muscle in arthropods is exactly the reverse.

"In all vertebrates, and in none other, the axis of this skeleton is a jointed backbone (vertebral column) inclosing and protecting the nervous centers (cerebro-spinal axis). These, therefore, may well be called backboned animals.

"All vertebrates, and none other, have a number of their anterior vertebral joints enlarged and consolidated into a box to form the skull, in order to inclose and protect a similar enlargement of the nervous center, viz., the brain; and also usually, but not always, a number of posterior joints, enlarged and consolidated to form the pelvis, to serve as a firm support to the hind-limbs.

"All vertebrates, and none other, have two cavities, inclosed and protected by the skeleton, viz., the neural cavity above, and the visceral or body cavity below, the vertebral column.

"All vertebrates, with few exceptions, and no other animals, have two and only two pair of limbs. The exceptions are of two kinds, viz.: (a) some lowest fishes, amphioxus and lampreys, which probably represent the vertebrate condition before limbs were acquired; and (b) degenerate forms like snakes and some lizards, which have lost their limbs by disuse.

"So much concerns the general plan of skeletal structures and is strongly suggestive of—in fact it is inexplicable without—common origin. But much more remains which is not only suggestive, but demonstrative of such origin. By extensive comparison in the taxonomic and ontogenic series, the whole vertebrate structure in all its details in different animals may be shown to be modifications one of another. Sometimes a piece is enlarged, sometimes diminished, or even becomes obsolete; sometimes several pieces are consolidated into one; but, in spite of all these obscurations, corresponding parts usually may be made out."

These remarkable similarities in the common general plan alone are convincing evidences of descent, but attention may be called to a like similarity extending to the details of structure. For example: the wings of a bat (a mammal), a bird and a fossil flying reptile all show the same bones adaptively modified; a series of either fore or hind limbs of a mammal with one toe (horse), two toes (sheep), four toes (hog) and five toes (dog) exhibit a remarkable series of homologies pointing to a five-toed ancestor, and any other series of organs of vertebrates would give the same evidence of fundamental resemblances (homologies). For such a series of facts the reader must be referred to special books like Wiedersheim's "Comparative Anatomy of the Vertebrates," Romanes's "Darwin and After Darwin," and Le Conte's "Evolution."

The existence of great similarities in vertebrate structure is not always fully recognized. To the superficial observer the bodies of animals of different classes seem to differ fundamentally in plan, to be entirely different machines, made each for its own purposes, at once, out of hand. Extensive comparison, on the contrary, shows them to be the same, altho the essential identity is obscured by adaptive modifications. The simplest, in fact the only scientific, explanation of the phenomena of vertebrate structure is the idea of a primal vertebrate, modified more and more through successive generations by the necessities of different modes of life.

See, then, the difference between man's mode of working and Nature's. A man having made a steam-engine, and desiring to use it for a different purpose from that for which it was first designed and used, will nearly always be compelled to add new parts not contemplated in the original machine. Nature rarely makes new parts—never, if she can avoid it—but, on the contrary, adapts an old part to the new function. It is as if Nature were not free to use any and every device to accomplish her end, but were conditioned by her own plans of structure; as, indeed, she must be according to the derivation theory. Thus, in the fin of a fish, the fore-paw of a reptile or a mammal, the wing of a bird, and the arm and hand of a man, is found the same part, variously modified for many purposes.

Another striking class of the facts of morphology which admit of scientific explanation only along the line of homology are the thousands of cases of rudimentary or vestigial structures to be found. Throughout both the animal and vegetable kingdoms dwarfed and useless representatives of organs are constantly met with, which in other and allied kinds of animals and plants are of large size and functional utility. Thus, for instance, the unborn whale has rudimentary teeth, which are never destined to cut the gums; and throughout its life this animal retains, in a similarly rudimentary condition, a number of organs which never could have been of use to any kind of creature save a terrestrial quadruped.

Other well-known examples among vertebrates are: Vestiges of hind limbs in certain snakes, reduced wings in the Apteryx and ostriches, rudiments of eyes in cave fishes, hind limbs beneath the skin of whales, the vermiform appendix in man, as well as useless muscles to move the ears and the skin, and also a very much reduced hairy covering over the surface of the body. Wiedersheim has recorded more than one hundred and eighty such structural reminiscences in man.

Now, rudimentary organs of this kind are of such frequent occurrence, that almost every species of organism presents one or more of them—usually, indeed, a considerable number. How, then, are they to be accounted for? Of course the theory of descent with adaptive modification has a simple answer to supply—namely, that when, from changed conditions of life, an organ which was previously useful becomes useless, it will be suffered to dwindle away in successive generations, under the influence of certain natural causes.

There are people who are inclined to doubt the importance of the consideration of these vestigial structures, and query what possible importance these may have. A simple illustration may serve to make this clear.

Suppose that every description and every picture of a bicycle were destroyed, and that the race of modern motorcycles remained. Would it not be likely, a hundred years hence, for some historian to speak of the "inspiration" of the motorcycle in the mind of some great inventor in the early part of the Twentieth Century? But suppose, after this statement was made, that in some small museum in England, one of the old hobby-horses was found? Suppose that in the cellar or garret of some house in Australia or Canada, one of the old 52-inch wheel "bikes" was located. Suppose, again, that a Southerner had given to one of his colored servants an old "kangaroo" bicycle when he got a new one, and that the negro still occasionally used this over the road to the post-office. And suppose that an early style motor was discovered in a junk-shop. Would it not be possible to show how the modern motorcycle had come into existence?

It is in this very fashion that these rudimentary structures are of value. There would be no reason for the rudimentary hind legs of a snake, if it were not that, at one time, the ancestors of snakes were legged creatures. The scales on the legs of a chicken would be unexplainable unless the development of feathers from scales could also be shown by the fossil bird Archæopteryx.

Perhaps a still more humble example will show the perpetuation of useless things. On the back of a man's dress coat are two buttons. Why are they there? They were used to hold the scabbard of the walking sword that was a part of a gentleman's costume. The sword has gone, but the buttons remain. These customs among us are the vestigial structures of an earlier period of civilization.

A few salient facts will illustrate the kind of evidence to be deducted from embryology. Most remarkable is the "Recapitulation Doctrine," which is that individual development (ontogeny) recapitulates ancestral history (phylogeny). Illustrations quoted from the words of Romanes and Le Conte will make this principle clear. "It is an observable fact," says Romanes, "that there is often a close correspondence between developmental changes as revealed by any chronological series of fossils which may happen to have been preserved, and developmental changes which may be observed during the life-history of now existing individuals belonging to the same group of animals. For instance, the successive development of prongs in the horns of deer-like animals, which is so clearly shown in the geological history of this tribe, is closely reproduced in the life-history of existing deer. Or, in other words, the antlers of an existing deer furnish in their development a kind of "résumé," or recapitulation, of the successive phases whereby the primitive horn was gradually superseded by horns presenting a greater and greater number of prongs in successive species of extinct deer.

"Now, it must be obvious that such a recapitulation in the life-history of an existing animal of developmental changes successively distinctive of sundry allied, tho now extinct species, speaks strongly in favor of evolution. For as it is of the essence of this theory that new forms arise from older forms by way of hereditary descent, we should antecedently expect, if the theory is true, that the phases of development presented by the individual organism would follow, in their main outlines, those phases of development through which their long line of ancestors had passed. The only alternative view is that as species of deer, for instance, were separately created, additional prongs were successively added to their antlers; and yet that, in order to be so added to successive species, every individual deer belonging to later species was required to repeat in his own lifetime the process of successive additions which had previously taken place in a remote series of extinct species. Now I do not deny that this view is a possible view; but I do deny that it is a probable one. According to the evolutionary interpretation of such facts, we can see a very good reason why the life-history of the individual is thus a condensed "résumé" of the life-history of its ancestral species. But according to the opposite view no reason can be assigned why such should be the case."

"It is well known," likewise comments Le Conte, "that the embryo or larva of a frog or toad, when first hatched, is a legless, tail-swimming, water-breathing, gill-breathing animal. It is essentially a fish, and would be so classed if it remained in this condition. The fish retains permanently this form, but the frog passes on. Next, it forms first one pair and then another pair of legs; and meanwhile it begins to breathe also by lungs. At this stage it breathes equally by lungs and by gills—*i.e.*, both air and water. Now, the lower forms of amphibians, such as siredon, menobranchus, siren, etc., retain permanently this form, and are therefore called 'perennibranchs,' but the frog still passes on. Then the gills gradually dry up, as the lungs develop, and they now breathe wholly by lungs, but still retain the tail. Now this is the permanent, mature condition of many amphibians, such as the triton, the salamander, etc., which are therefore called "caducibranchs," but the frog still passes on. Finally, it loses the tail, or rather its tail is absorbed and its material used in further development, and it becomes a perfect frog, the highest order (anoura) of this class.

"Thus, then, in ontogeny the fish goes no further than the fish stages. The perennibranch passes through the fish stage to the perennibranch amphibian. The caducibranch takes first the fish-form, then the perennibranch-form, and finally the caducibranch-form, but goes no further. Last, the anoura takes first the fish-form, then that of the perennibranch, then that of the caducibranch, and finally becomes anoura. Now, this is undoubtedly the order of succession of forms in geological times—*i.e.*, in the phylogenic series. Fishes first appeared in the Devonian and Upper Silurian in very reptilian or rather amphibian forms. Then in the Carboniferous, fishes still continuing, there appeared the lowest—*i.e.*, most fish-like forms of amphibians. These were undoubtedly perennibranchs. In the Permian and Triassic higher forms appeared, which were certainly caducibranch. Finally, only in the Tertiary, so far as we yet know, do the highest form (anoura) appear. The general similarity of the three series is complete.

"It is a curious and most significant fact that the successive stages of the development of the individual in the higher forms of any group (ontogenic series) resemble the stages of increasing complexity of differentiated structure in ascending the animal scale in that group (taxonomic series), and especially the forms and structure of animals of that group in successive geological epochs (phylogenic series). In other words, the individual higher animal in embryonic development passes through temporary stages, which are similar in many respects to permanent or mature conditions in some of the lower forms in the same group.

"Surely this fact is wholly inexplicable except by the theory of derivation or evolution. The embryo of a higher animal of any group passes now through stages represented by lower forms, because in its evolution (phylogeny) its ancestors did actually have these forms. From this point of view the ontogenic series (individual history) is a brief recapitulation, as it were, from memory, of the main points of the philogenic series, or family history. We say brief recapitulation of the main points, because many minor points are dropped out. Even some main points of the earliest stages of the family history may be dropped out of this sort of inherited memory.

"This resemblance between the three series must not, however, be exaggerated. Not only are many steps of phylogeny, especially in its early stages, dropped out in the ontogeny, but, of course, many adaptive modifications for the peculiar conditions of embryonic life are added. But it is remarkable how even these—for example, the umbilical cord and placenta of the mammalian embryo—are often only modifications of egg-organs of lower animals, and not wholly new additions. It is the similarity in spite of adaptive modifications that shows the family history."

But even these recapitulations are not so convincing as are those of many internal structures which are not now of any possible use. In the fishes, the lowest class of vertebrates, gills are the organs of breathing. Water taken into the mouth is ejected from the throat through the gill-slits, which are lined with delicate vascular membranes. Blood circulating through these membranes absorbs oxygen from the water and gives off carbon dioxide gas. Thus in the fishes the gills play the part performed by lungs in higher forms, and are essential organs throughout life. Passing up the scale of animal life, amphibian embryos develop gill-slits and they are present and functionally active for a few days in the early life of certain tadpoles. In all amphibians the slits close soon and the fully developed frogs and salamanders do not use them for breathing. Certain amphibians have gills throughout life, but they are not the gills corresponding to those of fishes.

Now, in interpreting these facts, it should be noted that the embryos of the higher classes, reptiles, birds and mammals, never have access to water and yet in every species whose development is known gill-slits are present in the embryos. For example, in a chick of three to five days' incubation there are four slits on the side of the neck. Likewise there are several gill-slits in human embryos of three to five weeks' development. In all reptiles, birds and animals the gill-slits, however, are temporary; they serve no function and close long before hatching or birth. The only interpretation which appeals to the biologist as reasonable is that gill-slits in the higher vertebrates are reminiscences of ancestral history and, originally fish organs, they appear regularly in the fish-like stage of every embryo of higher forms which in their development pass through stages comparing in a general way to the adults of lower forms.

There are dozens and dozens of similar cases known to occur in the embryology of vertebrates. The notochord, which is the dorsal stiffening axis in the lowest vertebrate (amphioxus), appears in the embryos of all higher forms. In them it is purely temporary and disappears as the backbone is developed around it. The lungs of amphibia and higher forms develop in the embryo identically with the air-bladder of fishes.

In the embryonic development of man and other mammals three pairs of kidneys are formed, only one remaining at birth. The first kidneys (pronephros) develop in the stage when gills and other structures correspond to a fish-embryo stage, and in some of the lowest fishes this pair becomes the permanent kidneys. The second kidneys (mesonephros) correspond to an amphibian-reptilian stage, and this pair persists throughout life in the amphibia, in the embryos of which the first kidneys are temporarily present. The third kidneys (metanephros) succeed the first and second in mammalian development and remain throughout life. In the higher forms the first and second kidneys are absolutely useless. The only reasonable explanation of this fact is that the appearance of the first kidneys in amphibian embryos and of the first and second in mammalian embryos is due to this repetition or recapitulation of ancestral history.

If space permitted it would be easy to present abundance of additional evidence to the same effect from the development of the skeleton, the skull, the brain, the sense-organs, and, in short, of every constituent part of the vertebrate organization. Even without any anatomical dissection, the similarity of all vertebrate embryos at comparable stages of development admits of being strikingly shown, if the embryos are merely placed one beside the other. Here, for instance, are the embryos of a fish, a salamander, a tortoise, a bird, and four different mammals. In each case three comparable stages of development are represented. Now if the series is read horizontally, it can be seen that there is very little difference between the eight animals at the earliest of the three stages represented—all having fish-like tails, gill-slits, and so on. In the next stage further differentiation has taken place, but it will be observed that the limbs are still so rudimentary that even in the case of man they are considerably shorter than the tail. But in the third stage the distinctive characters are well marked.

So far examples have been drawn entirely from the vertebrate animals; it should be pointed out, however, that there is a repetition of just the same kind of evidence in all the other groups of animals, and as well in the plant kingdom. When all this mass of evidence is taken together, it is not to be wondered at that the science of comparative embryology should be considered as the principal witness to the theory of descent.

But why should ontogeny repeat the steps of phylogeny? Professor Le Conte replies that "the general answer is doubtless to be found in the law of heredity—that wonderful law, so characteristic of living things. We have compared it to a brief recapitulation from memory—the minor points, especially if they be also early, dropping out. But can we not explain it further? It is probable that we find a more special explanation in "the law of acceleration," first brought forward by Prof. Cope. By the law of heredity each generation repeats the form and structure of the previous, and in the order in which they successively appeared. But there is a tendency for each successively appearing character to appear a little earlier in each successive generation; and by this means time is left over for the introduction of still higher new characters. Thus, characters which were once adult are pushed back to the young, and then still back to the embryo, and thus place and time are made for each generation to push on still higher. The law of acceleration is a sort of young-Americanism in the animal kingdom. If our boys acquire knowledge and character similar to that of adults of a few generations back, they will have time while still young and plastic to press forward to still higher planes."

These similarities or homologies of embryology appeal to the thinker, as has been said, as explainable only on the theory of descent.

Agassiz, however, held an opposing view. His statements on this point are classical in biological literature. He says: "If we now pass to the highest type of the Animal Kingdom, the Vertebrates, there is no lack of evidence to show the identity in their mode of development, as well as the striking resemblance of the young in their earliest stages of growth. The young Fish, the young Reptile, the young Bird, the young Mammal, resemble one another to an astonishing degree, while they have not one feature in their mode of growth which recalls either the Articulate, the Mollusk, or the Radiate. It is, therefore, not true, tho so often stated, that in their development the higher animals pass successively through the condition of all the lower ones; while it is emphatically true that in each of the four great branches of the Animal Kingdom there is a common mode of development. It is equally true that in certain features the higher classes of each branch in their younger condition recall the characteristic features of the lower ones, tho each class has its own structural character, and early diverges from the common starting-point.

"Indeed, modern Embryology leads at once to the consideration of the most occult problem, as to the origin of animals, suggested by these comparisons. What do these resemblances mean, from some of which we shrink as unnatural and even revolting? If we put a material interpretation upon them, and believe that even Man himself has been gradually developed out of a fish, they are repugnant to our better nature. But looked at in their intellectual significance, they truly reveal the unity of the organic conception of which Man himself is a part, and mark not only the incipient steps in its manifestation, but also, with equal distinctness, every phase in its gradual realization. They mean that when the first Fish was called into existence, the Vertebrate type existed as a whole in the creative thought, and the first expression of it embraced potentially all the organic elements of that type, up to Man himself. To me the fact that the embryonic form of the highest Vertebrate recalls in its earlier stage the first representatives of its type in geological times and its lowest representatives at the present day, speaks only of an ideal relation, existing not in the things themselves, but in the mind that made them.

"It is true that the naturalist is sometimes startled at these transient resemblances of the young among the higher animals in one type to the adult condition of the lower animals in the same type; but it is also true that he finds each one of the primary divisions of the Animal Kingdom bound to its own norm of development, which is absolutely distinct from that of all the others; it is also true, that while he perceives correspondence between the early phases of the higher animals and the mature state of the lower ones, he never sees any one of them diverge in the slightest degree from its own structural character—never sees the lower rise by a shade beyond the level which is permanent for the group to which it belongs—never sees the higher ones stop short of their final aim, either in mode or extent of their transformation.

"I cannot repeat too emphatically, that there is not a single fact in embryology to justify the assumption that the laws of development, now known to be so precise and definite for every animal, have ever been less so, or have ever been allowed to run into each other. The philosopher's stone is no more to be found in the organic than the inorganic world; and we shall seek as vainly to transform the lower animal types into the higher ones by any of our theories, as did the alchemists of old to change the baser metals into gold."

Thus did Agassiz reject the theory of descent in the face of the most overwhelming evidence. For forty years after his expression the whole force of biology tended to the other side of the scale. But steadily, as time went on, the great co-discoverer of natural selection, Alfred Russel Wallace, became less and less satisfied with the wholesale elimination of purpose in natural affairs. Even Haeckel—the most outspoken of the anti-theists—suggested that the " 'house of God' served to raise man above the misery and prose of daily life, to lift him into the sacred, poetic atmosphere of a higher, ideal world." That was a good deal for Haeckel to say. Wallace went further. Summarizing his life work as contemporary with Darwin, he said: "I do not find myself in a position, now, to agree with my brother naturalist to the end that God is left out of the world. It seems to my mind that a Higher Cause necessarily must exist. Merely to call such a Higher Cause 'Nature' instead of 'God' appears to me more than a mere substitution of terms. Words come to have meanings associated with them, in addition to the meanings that etymologically may be ascribed to them, and 'Nature' is a colder term than 'God.' "

The veteran naturalist amplifies this thesis in passages in many of his books. He points out that the "red ruth of tooth and claw" is a necessary sequence of the "extinction of the unfittest." At the same time, he is careful to point out that the extinction of the unfittest is the only way of showing consideration to those that remain. One of the weaknesses of modern civilization is that of forcing the working population to support vast hordes of mental defectives, epileptics, incurably insane and crime-twisted classes. That a man or a woman should be handicapped all through life to support a brother or sister in an institution because of the sins of the parents is an anomaly that Nature, in her own way, never permits.

No one can deny—it is beyond denial—that species have originated by natural forces, of which selection is one of the most powerful. But, on the other hand, no one can assert that these causes are self-caused, or that they happen by chance. No one can deny, again, that the association between organic and inorganic matter is very close. But, on the other hand, no one can assert that this gulf is bridgeable by the chemist. Lastly, it may be said with unquestioned emphasis that irreverence and flippancy in the relationships between Biology and Theology are found mainly among the immature scientific doctrinaires, the older and more profoundly versed scholars are finding that mechanical explanations for life and life processes are inadequate.

CHAPTER XI

EVIDENCES OF ORGANIC DEVELOPMENT

If a child in the kindergarten be given an assortment of cards of various colors and shapes and a number of boxes into which to put them, it becomes evident that the natural tendency is to group together the cards according to their striking resemblances, for most children probably of color. This is simply an elementary exercise in classification and in fundamentals is parallel with the accepted grouping of plants and animals on the basis of resemblances. Many authors have discussed the bearing of classification on the theory of descent, and among the best is the popular statement of the case by Romanes.

"It is a matter of observable fact," he remarks, "that different forms of plants and animals present among themselves more or less pronounced resemblances. From the earliest times, therefore, it has been the aim of philosophical naturalists to classify plants and animals in accordance with these resemblances. Of course the earliest attempts at such classification were extremely crude. The oldest of these attempts with which we are acquainted—namely, that which is presented in the books of Genesis and Leviticus—arranges the whole vegetable kingdom in three simple divisions of Grass, Herbs and Trees, while the animal kingdom is arranged with almost equal simplicity with reference first to habitats in water, earth or air and next as to modes of progression. These, of course, were what may be termed common-sense classifications, having reference merely to external appearances and habits of life.

"But when Aristotle laboriously investigated the comparative anatomy of animals, he could not fail to perceive that their entire structures had to be taken into account in order to classify them scientifically and also that for this purpose the internal parts were of quite as much importance as the external. Indeed, he perceived that they were of greatly more importance in this respect, inasmuch as they presented so many more points for comparison, and in the result he furnished an astonishingly comprehensive as well as an astonishingly accurate classification of the larger groups of the animal kingdom. On the other hand, classification of the vegetable kingdom continued pretty much as it had been left by the book of Genesis—all plants being divided into three groups, Herbs, Shrubs and Trees. Nor was this primitive state of matters improved upon till the sixteenth century, when Gesner, and still more Cesalpino, laid the foundations of systematic botany.

"But the more that naturalists prosecuted their studies on the anatomy of plants and animals, the more enormously complex did they find the problem of classification become. Therefore they began by forming what are called artificial systems in contradistinction to natural systems. An artificial system of classification is a system based on the more or less arbitrary selection of some one part or set of parts, while a natural classification is one that is based upon a complete knowledge of all the structures of all the organisms which are classified.

"Thus the object of classification has been that of arranging organisms in accordance with their natural affinities, by comparing organism with organism, for the purpose of ascertaining which of the constituent organs are of the most invariable occurrence and therefore of the most typical signification. A porpoise, for instance, has a large number of teeth, and in this feature resembles most fish, while it differs from all mammals. But it also gives suck to its young. Now, looking to these two features alone, should we say that a porpoise ought to be classed as a fish or as a mammal? Assuredly as a mammal, because the number of teeth is a very variable feature both in fish and mammals, whereas the giving of suck is an invariable feature among mammals and occurs nowhere else in the animal kingdom.

"This, of course, is chosen as a very simple illustration. Were all cases as obvious, there would be but little distinction between natural and artificial systems of classification. But it is because the lines of natural affinity are, as it were, so interwoven throughout the organic world, and because there is, in consequence, so much difficulty in following them that artificial systems have to be made in the first instance as feelers toward eventual discovery of the natural system. In other words, while forming their artificial systems of classification, it has always been the aim of naturalists—whether consciously or unconsciously—to admit as the bases of their system those characters which, in the then state of their knowledge, seemed most calculated to play an important part in the eventual construction of the natural system.

"If we were dealing with the history of classification, it would here be interesting to note how the course of it has been marked by gradual change in the principles which naturalists adopted as guides to the selection of characters on which to found their attempts at a natural classification. Some of these changes, indeed, I shall have to mention later on, but at present what has to be specially noted is that through all these changes of theory or principle and through all the ever-advancing construction of their taxonomic science naturalists themselves were unable to give any intelligible reason for the faith that was in them or the faith that over and above the artificial classifications which were made for the mere purpose of cataloguing the living library of organic nature, there was deeply hidden in nature itself a truly natural classification, for the eventual discovery of which artificial systems might prove to be of more or less assistance.

"Linnæus, for example, expressly says, 'You ask me for the characters of the natural orders; I confess that I cannot give them.' Yet he maintains that, altho he cannot define the characters, he knows, by a sort of naturalist's instinct, what in a general way will subsequently be found to be the organs of most importance in the eventual grouping of plants under a natural system. 'I will not give my reasons for the distribution of the natural orders which I have published,' he said; 'you, or some other person, after twenty or after fifty years, will discover them and see that I was right.' Thus we perceive that in forming their provisional or artificial classifications, naturalists have been guided by an instinctive belief in some general principle of natural affinity, the character of which they have not been able to define, and the structures which they selected as the basis of their classifications when these were consciously artificial were selected because it seemed that they were the structures most likely to prove of use in subsequent attempts at working out the natural system.

"This general principle of natural affinity, of which all naturalists have seen more or less well-marked evidence in organic nature, and after which they have all been feeling, has sometimes been regarded as natural, but more often as supernatural. Those who regard it as supernatural took it to consist in a divine ideal of creation according to types, so that the structural affinities of organisms were to them expressions of an archetypal plan, which might be revealed in its entirety when all organisms on the face of the earth should have been examined. Those, on the other hand, who regarded the general principle of affinity as depending on some natural causes, for the most part concluded that these must have been utilitarian causes; or, in other words, that the fundamental affinities of structure must have depended upon fundamental requirements of function. According to this view, the natural classification would eventually be found to stand upon a basis of physiology.

"Therefore all the systems of classification up to the earlier part of the present century went upon the apparent axiom that characters which are of most importance to the organisms presenting them must be characters most indicative of natural affinities. But the truth of the matter was eventually found to be otherwise. For it was eventually found that there is absolutely no correlation between these two things; that, therefore, it is a mere chance whether or not organs which are of importance to organisms are likewise of importance as guides to classification, and, in point of fact, that the general tendency in this matter is toward an inverse instead of a direct proportion. More often than not the greater the value of a structure for the purpose of indicating natural affinities, the less is its value to the creatures presenting it.

"Enough has now been said to show three things. First, that long before the theory of descent was entertained by naturalists, naturalists perceived the fact of natural affinities and did their best to construct a natural system of classification for the purpose of expressing such affinities. Second, that naturalists had a kind of instinctive belief in some one principle running through the whole organic world, which thus served to bind together organisms in groups subordinate to groups—that is, into species, genera, orders, families, classes, subkingdoms and kingdoms. Third, that they were not able to give any very intelligible reason for this faith that was in them; sometimes supposing the principle in question to be that of a supernatural plan of organization, sometimes regarding it as dependent on conditions of physiology and sometimes not attempting to account for it at all.

"Of course it is obvious that the theory of descent furnishes the explanation which is required. For it is evident to modern writers that, altho these older naturalists did not know what they were doing when they were tracing these lines of natural affinity, and thus helping to construct a natural classification—I say it is now evident to evolutionists that these naturalists were simply tracing the lines of generic relationship. The great principle pervading organic nature, which was seen so mysteriously to bind the whole creation together as in a nexus of organic affinity, is now easily understood as nothing more or less than the principle of Heredity, as the term is now understood by biologists."

Darwin first called attention to this line of evidence for evolution in the following words: "Naturalists try to arrange the species, genera and families in each class on what is called the Natural System. But what is meant by this system? Some authors look at it merely as a scheme for arranging together those living objects which are most alike and for separating those which are most unlike or an artificial method of enunciating, as briefly as possible, general proportions—that is, by one sentence to give the characters common, for instance, to all mammals, by another those common to all carnivora, by another those common to the dog-genus, and then, by adding a single sentence, a full description is given of each kind of dog. The ingenuity and utility of this system are indisputable. But many naturalists think that something more is meant by the Natural System; they believe that it reveals the plan of the Creator. (It is always to be remembered that Darwin's attitude was essentially a religious one, and that he deplored the agnostic use of his arguments.) Expressions such as that famous by Linnæus, which we often meet with in a more or less concealed form, namely, that the characters do not make the genus, but that the genus gives the characters, seem to imply that some deeper bond is included in our classifications than mere resemblance. I believe that this is the case and that community of descent—the one known cause of close structural similarity in highly developed organic beings—is the bond which tho observed by various degrees of modification, is partially revealed to us by our classifications."

Before the days of Darwin naturalists had classified plants and animals on a tree-like plan and had rejected the old ladder series of early systematists. The tree system is the one which all naturalists regard as the true one. "According to this system," Romanes points out, "a short trunk may be taken to represent the lowest organisms which cannot properly be termed either plants or animals. This short trunk soon separates into two large trunks, one of which represents the vegetable and the other the animal kingdom. Each of these trunks then gives off large branches signifying classes, and these give off smaller but more numerous branches, signifying families, which ramify again into orders, genera and finally into the leaves, which may be taken to represent species. Now, in such a representative tree of life, the height of any branch from the ground may be taken to indicate the grade of organization which the leaves, or species, present; so that, if we picture to ourselves such a tree, we may understand that while there is a general advance of organization from below upward, there are many deviations in this respect. Sometimes leaves growing on the same branch are growing at a different level—especially, of course, if the branch be a large one, corresponding to a class or sub-kingdom. And sometimes leaves growing on different branches are growing at the same level; that is to say, altho they represent species belonging to widely divergent families, orders or even classes, it cannot be said that the one species is more highly organized than the other.

"Now, this tree-like arrangement of species in nature is an arrangement for which Darwin is not responsible. For, as we have seen, the detecting of it has been due to the progressive work of naturalists for centuries past, and even when it was detected, at about the commencement of the present century, naturalists were confessedly unable to explain the reason of it or what was the underlying principle that they were engaged in tracing when they proceeded ever more and more accurately to define these ramifications of natural affinity. But now we can clearly perceive that this underlying principle was none other than Heredity as expressed in family likeness—likeness, therefore, growing progressively more unlike with remoteness of ancestral relationship.

"First of all, and from the most general point of view, it is obvious that the tree-like system of classification, which Darwin found already and empirically worked out by the labors of his predecessors, is as suggestive as anything could well be of the fact of genetic relationship. For this is the form that every tabulation of family pedigree must assume, and therefore the mere fact that a scientific tabulation of natural affinities was eventually found to take the form of a tree is in itself highly suggestive of the inference that such a tabulation represents a family tree. If all species were separately created, there can be no assignable reason why the ideas of earlier naturalists touching the form which a natural classification would eventually assume should not have represented the truth—why, for example, it should not have assumed the form of a ladder (as was anticipated in the seventeenth century), or of a map (as was anticipated in the eighteenth), or, again, of a number of wholly unrelated lines, circles, etc. (as certain speculative writers of the nineteenth century have imagined). But, on the other hand, if all species were separately and independently created, it becomes virtually incredible that we should everywhere observe this progressive arborescence of characters common to larger groups into more and more numerous and more and more delicate ramifications of characters distinctive only of smaller and smaller groups. A man would be deemed insane if he were to attribute the origin of every branch and every twig of a real tree to a separate act of special creation, and altho we have not been able to witness the growth of what we may term in a new sense the Tree of Life, the structural relations which are now apparent between its innumerable ramifications bear quite as strong a testimony to the fact of their having been due to an organic growth as is the testimony furnished by the branches of an actual tree."

Summarizing, it is established that "all the general principles and particular facts appertaining to the natural classification of plants and animals are precisely what they ought to be according to the theory of genetic descent, while no one of them is such as might be—and, indeed, used to be—expected upon the theory of special creation.

"First of all we must take note that the classification of plants and animals in groups subordinate to groups is not merely arbitrary or undertaken only for a matter of convenience and nomenclature—such, for instance, as the classification of stars in constellations. On the contrary, the classification of a naturalist differs from that of an astronomer, in that the objects which he has to classify present structural resemblances and structural differences in numberless degrees, and it is the object of his classification to present a tabular statement of these facts. Now, long before the theory of evolution was entertained, naturalists became fully aware that these facts of structural resemblances running through groups subordinate to groups were really facts of nature and not merely poetic imaginations of the mind. No one could dissect a number of fishes without perceiving that they were all constructed on one anatomical pattern which differed considerably from the equally uniform pattern on which all mammals were constructed, even altho some mammals bore an extraordinary resemblance to fish in external form and habits of life. And similarly with all the small divisions of the animal and vegetable kingdoms.

"Everywhere investigation revealed the bonds of close structural resemblances between species of the same genus, resemblance less close between genera of the same family, resemblance still less close between families of the same order, resemblance yet more remote between orders of the same class and resemblance only in fundamental features between classes of the same sub-kingdom, beyond which limit all anatomical resemblance was found to disappear—the different sub-kingdoms being formed on wholly different patterns. Furthermore, in tracing all these grades of structural relationship, naturalists were slowly led to recognize that the form which a natural classification must eventually assume would be that of a tree, wherein the constituent brances would display a progressive advance of organization from below upward.

"Now we have seen that altho this tree-like arrangement of natural groups was as suggestive as anything could well be of all the forms of life being bound together by the ties of genetic relationship, such was not the inference which was drawn from it. With the theory of special creation putting in strong claims, naturalists either regarded the resemblance of type subordinate to type as expressive of divine ideals, manifested in such creation or else contented themselves with investigating the facts without venturing to speculate upon their philosophical import. But even those naturalists who abstained from committing themselves to any theory of archetypal plans did not doubt that facts so innumerable and so universal must have been due to some one coördinating principle—that, even tho they were not able to suggest what it was, there must have been some hidden bond of connection running through the whole of organic nature. Modern investigation declares it to be manifest that this hidden bond can be nothing else than heredity, and, therefore, that these earlier naturalists, altho they did not know what they were doing, were really tracing the lines of genetic descent as revealed by degrees of structural resemblance—that the arborescent grouping of organic forms which their labors led them to begin, and in large measure to execute, was in fact a family tree of life.

"Here, then, is the substance of the argument from classification. The mere fact that all organic nature thus incontestably lends itself to a natural arrangement of group subordinate to group, when due regard is paid to degrees of anatomical resemblance—this mere fact of itself tells so weightily in favor of descent with progressive modification in different lines, that even if it stood alone it would be entitled to rank as one of our strongest pieces of evidence. But, as we have seen, it does not stand alone. When we look beyond this large and general fact of all the innumerable forms of life being thus united in a tree-like system by an unquestionable relationship of some kind, to those smaller details in the science of classification which have been found most useful as guides for this kind of research, then we find that all these details, or empirically discovered rules, are exactly what we should have expected them to be, supposing the real meaning of classification to have been that of tracing lines of pedigree."

Equally illumining is the massed evidence from Paleontology. The record of the rocks as shown by fossils has always been one of the most important lines of evidence for the theory of descent. In Darwin's time the critics never grew tired of demanding proof from paleontology. A great deal of such proof has been brought forth, but paleontologists caution against expecting a complete record of the animal and plant life of the past. The record is very imperfect, "but," to quote from Metcalf's "Organic Evolution" "so far as it goes it is an actual record. Only very unusual circumstances will secure the preservation of any animal or plant as a fossil. An organism, or portion of an organism, to be so preserved usually must be hard; it must be buried beneath soil of the proper kind and when buried must be impregnated with mineral salts or in some other way preserved from disintegration.

"When once converted into a fossil it must escape destruction at the hands of those agencies that are constantly destroying the rocks; heat, pressure, the disintegration that comes from exposure to the atmosphere, abrasion by ice and especially erosion by water. The character of whole continents has been repeatedly changed by these agencies. No wonder then, since fossilization is rare and the destruction of fossils when once formed so easy, that our record of past faunas and floras is so scant. It is a cause for congratulation that we have so much of a record as we do possess. Thousands of species of fossil plants and animals are known, and as yet but a small portion of the earth has been searched." Attention will be given to but a few illustrations of the kind of record found in the fossil-bearing rocks, and those records naturally will be chosen that are fairly complete.

Turning to a few illustrations of the origin of particular species or organs, the same principle of gradual increase in complexity is found in coming from the older to the younger geological formations. The record of the evolution of branching antlers in the deer, as before mentioned, is fairly complete. The first deer in the early Miocene had no antlers at all. In the middle Miocene are found deer with twopronged antlers of small size. In the upper Miocene and lower Pliocene are found three-pronged antlers somewhat larger. In the later Pliocene four-pronged and five-pronged antlers and still larger are met, while in the Pleistocene clays are seen arborescent antlers like those of the modern deer.

Out of the mass of evidence, one further illustration must needs be sufficient. The record of the origin of the horse, worked out by American paleontologists from American fossils, is probably the best example of paleontological evidence of evolution. The horse is especially peculiar in the character of its feet and teeth, and attention will be directed to these points. In the lower Eocene rocks an animal, Phenacodus, about the size of a fox, is found having five well-developed toes on each foot, and with short and but moderately corrugated teeth. This is one of the simplest known relatives of the hoofed mammals, and from forms something like Phenacodus must have been developed the elephant, the rhinoceros, the hog, the sheep, the camel, and all the other hoofed mammals, including the horse and its long line of ancestors. Observe the steps in the transformation of the five-toed limb of a form like Phenacodus into the one-toed limb of the horse.

These are, of course, but illustrations of the kind of testimony which the study of the rocks contributes toward the proof of the theory of descent. There is, however, an enormous body of uniform evidence to prove two general facts of the highest importance in regard to the theory. The first of these general facts is that an increase in the diversity of types both of plants and animals has been constant and progressive from the earliest to the latest times, as it is rational to anticipate that it must have been on the theory of descent in ever-ramifying lines of pedigree. And the second general fact is that through all these branching lines of ever-multiplying types, from the first appearance of each of them to their latest known conditions, there is overwhelming evidence of one great law of organic nature—the law of gradual advance from the general to the special, from the low to the high, from the simple to the complex.

The argument for the theory of descent deduced from a comparative study of the phenomena of paleontology—the distribution of species in time—can be supplemented by a like argument derived from a comparative study of the phenomena of geographical distribution, a distribution of the species of to-day in space. In considering the distribution of living things on the earth, the first thing to be noted is that there is a decided difference in the animals and plants of different regions. At first sight, differences of climate and other physical conditions would seem to account for this, but there are many phenomena of distribution which cannot thus be explained. Countries exceedingly similar in climate and physical conditions may have quite a different fauna and flora, while those that are unlike may be characterized by similar species of plants and animals.

If regions in Australia, South Africa and western South America, between latitudes twenty-five and thirty-five degrees, are compared, it will be found that they are extremely similar in climate and physical conditions; yet it would not be possible to point out three faunas and floras more utterly dissimilar. Or, on the other hand, if the productions of South America south of latitude thirty-five be compared with those north of twenty-five degrees it will be noted that altho climatic conditions are decidedly different, these productions are incomparably more closely related than they are to the productions of Australia or Africa under almost the same climatic conditions.

The most interesting evidences of all, however, are derived from a study of distribution in combination with geological records. A good sample of this sort of evidence is to be found in the distribution of marsupials (kangaroos, bandicoots, etc.) over the earth. This singular and lowly organized type of mammals constitutes almost the sole representative of the class in Australia and New Guinea, while it is entirely unknown in Asia, Africa, or Europe. It reappears in America, where several species of opossums are found. This anomaly of distribution at first was a puzzle to evolutionists, for it seemed unreasonable to postulate an earlier direct connection of these countries, which are too distant from each other to allow for migration in any other way. When, however, the geological history of the marsupial is taken into consideration the difficulty vanishes, for fossil records give abundant evidence that at one time before the more complex types of mammals came into existence the marsupials were spread over the whole eastern and western hemispheres and that as the higher mammals developed they exterminated the more primitive marsupials, except that in Australia and New Guinea the earlier forms persisted and in America the opossums remained.

That this wide distribution of marsupials was possible in early geologic times is further supported by the fact that other geological evidence shows that Australia and New Guinea were once connected, or nearly connected, with the Malay Peninsula, making migration from the mainland possible. Moreover, the evidence shows that at that early time a very mild climate prevailed far up into the Arctic regions, hence it is not difficult to believe that migration from Europe and Asia was not unusual. There are many other kinds of evidence to be derived from the study of distribution, some of the illustrations being even more striking than those quoted, but these will be sufficient to show the relation of this kind of evidence to the doctrine of evolution.

The last line of evidence to be considered is that of "domestication." Every one is familiar with the great modifications which have been brought about in domestic animals, such as horses, cattle, dogs, pigeons, canary birds, etc.; in food plants, as cereals, cabbages, lettuce, radishes, berries, fruits, etc.; and in ornamental plants, as roses, carnations, dahlias, pansies and a host of other forms. Moreover, the ease with which varieties of a given form can be produced is attested to by the work of experimental breeders.

Moreover, many of these varieties differ markedly from the forms from which they were derived. "Even during the brief history of man," says Le Conte, "have been formed races of different domesticated animals and useful and ornamental plants, differing so greatly from each other that if found in the wild state they would unhesitatingly be called different species, or even in some cases different genera."

It is on this last point that objection is often taken to this line of proof. Are even the extreme artificial varieties of any form distinct species or must they be considered but varieties of the original form? This question shows the opportunity for opposing views hinging on the definition to be given to the term species.

It might well be asked, What are the differences between the artifically-made extreme varieties (often called races), equivalent, so far as difference of form is concerned, to species, and real natural species? On this question much technical discussion could be given. It will be necessary, however, to allude here only to the most broadly recognized difference, namely, that artificially-made varieties intercross freely in breeding, producing offspring which are indefinitely fertile, while natural species do not intercross.

A great deal of study has been given this phenomenon. Darwin sums up his attitude toward it as follows: "It can no longer be maintained that varieties when crossed are invariably quite fertile. From the great difficulty of ascertaining the infertility of varieties in a state of nature, for a supposed variety, if proved to be infertile in any degree, would almost universally be ranked as a species; from man attending only to external characters in his domestic varieties, and from such varieties not having been exposed for very long periods to uniform conditions of life; from these several considerations we may conclude that fertility does not constitute a fundamental distinction between varieties and species when crossed. The general sterility of crossed species may safely be looked at, not as a special acquirement or endowment, but as incidental on changes of an unknown nature in their sexual elements."

It is true that horticulturists and breeders are intent only on making varieties along the lines of use or beauty from man's standpoint—that is, in size, structure, color, habits, etc., so-called morphological varieties—and not on making physiological species. There is, however, little doubt that mutually infertile races could be bred if the selection of individuals for breeding should be chosen with this idea in mind. Breeders have not cared to breed with this object in view. On the contrary, cross-sterile varieties would be a positive disadvantage to them in limiting the range of their experiments.

The important point so far as evidence of the truth of organic descent is concerned is to be found in the known changes in type which have been seen to occur in domesticated animals and plants and in the diversity of forms which are known to have been derived from a few simpler types. As Professor Bailey has said, "If the prejudices of scientists respecting the so-called artificial production of species could be overcome, they could just as well draw their proofs of development from what has already been done with cultivated plants and domesticated animals as from similar results which might arise in the future from independent efforts."

The trend of the evidence which has been used to prove the truth of the theory of descent having been outlined, the various causes or factors which have brought about the development of species to their new forms demand attention. These bear within themselves many problems of no little subtlety and are borne out by certain correlations of facts which are of absorbing interest.

CHAPTER XII

NATURAL SELECTION

ALTHO concerning the truth of descent there is now no doubt in the minds of biologists, there are many and various views as to the causes or factors which have brought about the origin of species of plants and animals. Most prominent of the theories concerning the factors of evolution is that of Natural Selection. This theory was conceived independently by Darwin and Wallace, and strange to say, the idea came to both from the perusal of the same book, Malthus's "Essay on Population."

On reading this book in 1838 Darwin first conceived the idea of natural selection. But he writes, "I was so anxious to avoid prejudice that I determined not for some time to write even the briefest sketch of it. In June, 1842, I first allowed myself the satisfaction of writing a very brief abstract of my theory in pencil, in thirty-five pages, and this was enlarged during the summer of 1844 into one of 230 pages."

And Wallace writes: "In February, 1858, I was suffering from a rather severe attack of intermittent fever at Ternate, in the Moluccas, and one day while lying on my bed during the cold fit something led me to think of the 'positive checks' described by Malthus in his 'Essay on Population,' a work I had read several years before and which had made a deep and permanent impression on my mind. These checks . . . must, it occurred to me, act on animals as well as man . . . and while pondering vaguely on this fact, there suddenly flashed upon me the idea of the survival of the fittest. In the two hours that elapsed before my ague fit was over I had thought out almost the whole of the theory, and the same evening I sketched the draft of my paper and in the two succeeding evenings wrote it out in full and sent it by the next post to Mr. Darwin."

It thus appears, to use Professor Locy's words, "that the announcement of the Darwin-Wallace theory of natural selection was made in 1858 and in the following year was published in the book, the famous "Origin of Species," upon which Darwin had been working when he received Mr. Wallace's essay." The theory has come to bear Darwin's name and is frequently referred to as "Darwinism."

From time to time there appear articles and pamphlets bearing many titles announcing the decline of Darwinism, and in many periodicals this is often taken to mean that certain scientific men are giving up the theory of descent. This is not the case. The truth is simply that some scientific men do not accept Darwin's natural selection explanation of the causes which brought about the descent of species. But Darwin's whole theory of natural selection might be discarded without injuring the general theory of descent, for the facts outlined in preceding pages have no necessary relation to theories as to causes—natural selection or other theories.

The confusion on this point is doubtless emphasized in the popular mind because Darwin not only set forth his natural selection theory in his book, the full title of which is "The Origin of Species by Means of Natural Selection; or, the Preservation of Favored Races in the Struggle for Life," but he also argued for the truth of development so well that it came to be generally accepted. However, the general idea of descent was clearly mapped out long before Darwin's time and he simply put the evidence into more convincing form. Hence development progress is not Darwin's theory, but natural selection (a factor) deserves to bear his name.

In order to grasp the full significance of natural selection, it is first necessary to appreciate the astounding facts relating to the struggle for existence. On this point Darwin's classical statement deserves to be given. "The elder De Candolle and Lyell," he said, "have largely and philosophically shown that all organic beings are exposed to severe competition. Nothing is easier than to admit in words the truth of the universal struggle for life, or more difficult than constantly to bear this conclusion in mind. Yet unless it be thoroly ingrained in the mind, the whole economy of nature, with every fact on distribution, rarity, abundance, extinction and variation, will be dimly seen or quite misunderstood. We behold the face of nature bright with gladness, we often see superabundance of food; we do not see, or we forget, that the birds which are idly singing round us mostly live on insects or seeds, and are thus constantly destroying life; or we forget how largely these songsters, or their eggs, or their nestling are destroyed by birds and beasts of prey; we do not always bear in mind that altho food may be now superabundant, it is not so at all seasons of each recurring year.

"I should premise that I use the term 'struggle for existence' in a large and metaphorical sense, including dependence of one being on another and including not only the life of the individual, but success in leaving progeny. Two canine animals, in a time of dearth, may be truly said to struggle with each other which shall get food and live. But a plant on the edge of a desert is said to struggle for life against the drought, tho more properly it should be said to be dependent on the moisture. A plant which annually produces a thousand seeds, of which only one of an average comes to maturity, may be more truly said to struggle with the plants of the same and other kinds which already clothe the ground. The mistletoe is dependent on the apple and a few other trees, but can only in a far-fetched sense be said to struggle with these trees, for, if too many of these parasites grow on the same tree, it languishes and dies. But several seedling mistletoes, growing close together on the same branch, may more truly be said to struggle with each other. As the mistletoe is disseminated by birds, its existence depends on them; and it may metaphorically be said to struggle with other fruit-bearing plants in tempting the birds to devour and thus disseminate its seeds. In these several senses, which pass into each other, I use for convenience' sake the general term of Struggle for Existence.

"A struggle for existence inevitably follows from the high rate at which all organic beings tend to increase. Every being which during its natural lifetime produces several eggs or seeds must suffer destruction during some period of its life and during some season or occasional year, otherwise, on the principle of geometrical increase, its numbers would quickly become so inordinately great that no country could support the product. Hence, as more individuals are produced than can possibly survive, there must in every case be a struggle for existence, either one individual with another of the same species, or with the individuals of distinct species, or with the physical conditions of life. Altho some species may be now increasing, more or less rapidly, in numbers, all cannot do so, for the world would not hold them.

"There is no exception to the rule that every organic being naturally increases at so high a rate that, if not destroyed, the earth would soon be covered by the progeny of a single pair. Even slow-breeding man has doubled in twenty-five years, and at this rate in less than a thousand years there would literally not be standing-room for his progeny. Linnæus has calculated that if an annual plant produced only two seeds—and there is no plant so unproductive as this—and their seedlings next year produced two, and so on, then in twenty years there would be a million plants. The elephant is reckoned the slowest breeder of all known animals, and I have taken some pains to estimate its probable minimum rate of natural increase; it will be safest to assume that it begins breeding when thirty years old and goes on breeding till ninety years old, bringing forth six young in the interval and surviving till one hundred years old; if this be so, after a period of from 740 to 750 years there would be nearly nineteen million elephants alive, descended from the first pair.

"But we have better evidence on this subject than mere theoretical calculations, namely, the numerous recorded cases of the astonishingly rapid increase of various animals in a state of nature, when circumstances have been favorable to them during two or three following seasons. Still more striking is the evidence from our domestic animals of many kinds which have run wild in several parts of the world. If the statements of the rate of increase of slow-breeding cattle and horses in South America, and latterly in Australia, had not been well authenticated, they would have been incredible. So it is with plants; cases could be given of introduced plants which have become common throughout whole islands in a period of less than ten years.

"There are plants which now range in India from Cape Comorin to the Himalaya which have been imported from America since its discovery. In such cases, and endless others could be given, no one supposes that the fertility of the animals or plants has been suddenly and temporarily increased in any sensible degree. The obvious explanation is that the conditions of life have been highly favorable, and that there has consequently been less destruction of the old and young, and that nearly all the young have been enabled to breed. Their geometrical ratio of increase, the result of which never fails to be surprising, simply explains their extraordinarily rapid increase and wide diffusion in their new homes.

"In a state of nature almost every full-grown plant annually produces seed, and among animals there are very few which do not annually pair. Hence we may confidently assert that all plants and animals are tending to increase at a geometrical ratio—that all would rapidly stock every station in which they could anyhow exist—and that this geometrical tendency to increase must be checked by destruction at some period of life. Our familiarity with the larger domestic animals tends, I think, to mislead us; we see no great destruction falling on them, but we do not keep in mind that thousands are annually slaughtered for food, and that in a state of nature an equal number would have somehow to be disposed of.

"The only difference between organisms which annually produce eggs or seeds by the thousand and those which produce extremely few is that the slow-breeders would require a few more years to people, under favorable conditions, a whole district, let it be ever so large. The condor lays a couple of eggs and the ostrich a score, and yet in the same country the condor may be the more numerous of the two; the Fulmar petrel lays one egg, yet it is believed to be the most numerous bird in the world. One fly deposits hundreds of eggs and another, like the hippobosca, a single one; but this difference does not determine how many individuals of the two species can be supported in a district. A large number of eggs is of some importance to those species which depend on a fluctuating amount of food, for it allows them rapidly to increase in number.

"But the real importance of a large number of eggs or seeds is to make up for much destruction at some period of life; and this period in the great majority of cases is an early one. If an animal can in any way protect its own eggs or young, a small number may be produced, and yet the average stock be fully kept up; but if many eggs or young are destroyed, many must be produced or the species will become extinct. It would suffice to keep up the full number of a tree which lived on an average for a thousand years if a single seed were produced once in a thousand years, supposing that this seed were never destroyed and could be insured to germinate in a fitting place. So that, in all cases, the average number of any animal or plant depends only indirectly on the number of its eggs or seeds.

"In looking at Nature, it is most necessary to keep the foregoing considerations always in mind—never to forget that every single organic being may be said to be striving to the utmost to increase in numbers; that each lives by a struggle at some period of its life; that heavy destruction inevitably falls either on the young or old during each generation or at recurrent intervals. Lighten any check, mitigate the destruction ever so little, and the number of the species will almost instantaneously increase to any amount."

Many marvelous facts concerning the rapid increase of plants and animals have been collected since Darwin's time. Jordan and Kellogg give many instances and among them the following: "It is said that the conger eel lays 15,000,000 eggs yearly. If each hatched and the conger grew to maturity, in a few years there would be no room for any other kind of fish in the sea. The codfish has been known to produce 9,100,000 eggs each year. If each egg were to develop, in ten years the sea would be solidly full of codfish. The female quinnat salmon of the Columbia ascends the river at the age of about four years and lays 4,000 eggs, after which she dies. Half these eggs develop into males. If each female egg came to maturity, we should have at the end of fifty years 8,000,000,000,000,000,000,000,000,000,000,000,000,000 female salmon and as many males as the offspring of a single pair. It takes about one hundred of these salmon to weigh a ton. Could all these fishes develop, in a very short time there would be no room for them in all the rivers of the North nor in all the waters of the sea."

The records of the spread of the English sparrow in America and of rabbits in Australia are splendid examples of the possible rate of multiplication. Professor Sidney Dickinson gives the following notes on the rabbit of Australia: "The fecundity of the rabbit is amazing, and his invasion of remote districts swift and mysterious. Careful estimates show that under favorable conditions a pair of Australian rabbits will produce six litters a year, averaging five individuals each. As the offspring themselves begin breeding at the age of six months, it is shown that at this rate, the original pair might be responsible in five years for progeny of over twenty millions. That the original score that were brought to the country have propagated after some such ratio, no one can doubt who has seen the enormous hordes that now devastate the land in certain districts. In all but the remoter sections the rabbits are now fairly under control; one rabbiter with a pack of dogs supervises stations where one hundred were employed ten years ago, and with ordinary vigilance the squatters have little to fear. Millions of the animals have been killed by fencing in the water holes and dams during a dry season, whereby they died of thirst and lay in enormous piles against the obstructions they had frantically and vainly striven to climb, and poisoned grain and fruit have killed myriads more."

These examples must suffice. Any other animals or plants would illustrate the same principle, for each increases at a rate which would make it cover the earth in a comparatively short time. That this is not the case is due to this check known as the Struggle for Existence. This was well known before Darwin's time, but he was the first to see its great importance in the development of plant and animal species.

The nature of the checks to increase is often complex. One has but to watch a bit of natural land to see them working. Climatic conditions play an important part in limiting the increase, and a wet season will make some crops exceedingly light and many insects very rare. Overcrowding limits the supply of food and other needful things, and hence some plants are "choked" and many animals starve. Serving as prey to other animals causes enormous destruction of both animals and plants, for thousands of insects and other animal enemies must have food. Thus Darwin in an observational experiment noted that out of 357 weed seedlings under observation 295 were destroyed by insects alone. Various bacterial and other fungous diseases destroy countless thousands of plants and animals in a single day, and it is well known that various diseases due to animal and vegetable parasites are great checks to increase in most species of vertebrate animals.

In some cases the struggle is with the elements, in others special enemies constitute the most important check. The history of the cottony-cushion scale in America, described by Miall, offers a good example of a special check of this sort. "About the year 1880 the orange groves of South California seemed to be infected with a kind of leprosy. White patches appeared on the trunks and branches, which at length ran together and covered the bark, the leaves turned yellow, and no fruit could be ripened. The plague spread with rapidity, and all the time-honored remedies were found to be ineffectual. It was soon made known that the symptoms described were due to the attack of a scale-insect, known in America as the fluted scale, or cottony-cushion scale.

"This formidable plague gradually increased its range, in spite of the vigorous use of poisonous washes. It was not till 1888 that an effectual remedy was found. The late C. V. Riley, Entomologist to the United States Department of Agriculture, had anxiously considered the ways of checking the fluted scale. He found out that it came from Australia, where it infested the bushes called wattles (Acacias); that it had been introduced into California about 1868, probably on Acacias; that in its native country it was not a serious plague, altho no remedies were employed. He concluded that it must be kept down in Australia by natural enemies of some kind which did not exist in California and that the real policy was to discover and import these remedies, whether parasitic or predatory.

"In 1888 Riley sent a trained entomologist, Albert Koebele, to visit Australia, examine the gardens and report. He found that the fluted scale, tho widespread, was kept in check by several insect foes. The most promising of these for Californian purposes was considered to be an Australian lady-bird known to naturalists as 'Vedalia cardinalis.' This beetle, both as larva and adult, greedily devours the scale-insect and its eggs, preys upon no other species and is very prolific. Koebele was diligent in procuring an abundant supply of Vedalia. The lady-birds were soon distributed and found plenty of occupation. In a year and a half they had practically rid California of the pest."

Nor is this case of the cottony-cushion scale alone. Any text-book of economic entomology will cite hundreds of cases of similar kinds. At the present time the United States entomologist, Dr. O. L. Howard, is searching for a special enemy supposed to keep in check the gipsy moth, now so destructive in Massachusetts.

Such are some of the influences known to affect plants and animals in the struggle for existence. It is clearly to be seen that the whole question of the relation of the individual to its environment—that is, the problems of plant and animal ecology—are involved in the struggle for existence and in the checks to the tendency to overwhelming increase. Science has only begun to understand these problems of ecology. However, the principle of the struggle for existence is not affected because its causes are not known. This much is certain: organisms tend to increase rapidly; an untiring struggle for existence exists; the vast majority of individuals perish as a result of this struggle with the environment—the result being as Darwin believed that those organisms best fitted to their environment survive—*i.e.*, the struggle for existence leads naturally to the survival of the fittest. This is natural selection. Nature—meaning the sum total of the environmental factors which affect an organism—selects those individuals best fitted to the environment. How this works in detail is best explained after some consideration of the variation of organisms.

The foundation of the Darwinian theory is the variability of species, and it is quite useless to attempt even to understand that theory much less to appreciate the completeness of the proof of it, unless a clear conception of the nature and extent of this variability is obtained. Variation in the state of nature has been discussed by Alfred Russell Wallace in "Darwinism." Mr. Wallace shows in some detail that individual variability is a general character of all common and widespread species of animals or plants; and, further, that this variability extends, so far as is known, to every mental faculty, and that each part or organ varies to a considerable extent independently of other parts. Again, he shows by abundant evidence that the variation that occurs is very large in amount—usually reaching 10 or 20 and sometimes even 25 per cent. of the average size of the varying part.

But a few examples can be given to illustrate this feature of life. The variability of plants is notorious, being proved not only by the endless variations which occur whenever a species is largely grown by horticulturists, but also by the great difficulty that is felt by botanists in determining the limits of species in many large genera. As an example may be taken the roses. In Mr. Baker's "Revision of the British Roses" he includes under the single species Rosa canina—the common dog-rose—no less than twenty-eight named varieties distinguished by more or less constant characters and often confined to special localities, and to these are referred about seventy of the species of British and continental botanists.

Concerning individual variation, the distinguished botanist, Alp. de Candolle, made a special study of the oaks of the whole world and has stated some remarkable facts as to their variability. He declares that on the same branch of oak he has noted the following variations: In the length of the petiole, as one to three; in the form of the leaf, being either elliptical or obovoid; in the margin being entire, or notched, or even pinnatifid; in the extremity being acute or blunt; in the base being sharp, blunt or cordate; in the surface being pubescent or smooth; the perianth varies in depth and lobing; the stamens vary in number, independently; the anthers are mucronate or blunt; the fruit stalks very greatly in length, often as one to three; the number of fruits varies; the form of the base of the cup varies; the scales of the cup vary in form; the proportions of the acorns vary; the times of the acorns' ripening and falling vary. Besides this, many species exhibit well-marked varieties which have been described and named.

Among birds copious evidence of variation is found. The most systematic observations on the individual variation of birds has been made by J. A. Allen in his remarkable memoir, "On the Mammals and Winter Birds of East Florida." He says: "The facts of the case show that a variation of from 15 to 20 per cent. in general size, and an equal degree of variation in the relative size of different parts, may be ordinarily expected among specimens of the same species and sex, taken at the same locality, while in some cases the variation is even greater than this." He then goes on to show that each part varies to a considerable extent independently of the other parts, so that when the size varies, the proportions of all the parts vary, often to a much greater amount. The wing and tail, for example, besides varying in length, vary in the proportionate length of each feather, and this causes their outline to vary considerably in shape. The bill also varies in length, width, depth and curvature.

Even tho one has not been impressed with the great variety of individuals in the state of nature, variation in domesticated plants and animals and the efficacy of artificial selection in producing varieties of the different species of plants and animals cannot have escaped notice. The following paragraphs are taken from Mr. Wallace's account of variation in domesticated plants and animals:

"Every one knows that in each litter of kittens or of puppies no two are alike. Even in the case in which several are exactly alike in colors, other differences are always perceptible to those who observe them closely. They will differ in size, in the proportions of their bodies and limbs, in the length or texture of their hairy covering and notably in their disposition. They each possess, too, an individual countenance, almost as varied when closely studied as that of a human being. The same thing occurs in the vegetable kingdom. All plants raised from seed differ more or less from each other. In every bed of flowers or of vegetables we shall find, if we look closely, that there are countless small differences in the size, in the mode of growth, in the shape or color of the leaves, in the form, color or markings of the flowers, or in the size, form, color or flavor of the fruit. These differences are usually small, but are yet easily seen, and in their extremes are very considerable; and they have this important quality, that they have a tendency to be reproduced, and thus by careful breeding any particular variation or group of variations can be increased to an enormous extent—apparently to any extent not incompatible with the life, growth and reproduction of the plant or animal.

"The way this is done is by artificial selection, and it is very important to understand this process and its results. Suppose we have a plant with a small edible seed and we want to increase the size of that seed. We grow as large a quantity of it as possible, and when the crop is ripe we carefully choose a few of the very largest seeds or we may by means of a sieve sort out a quantity of the largest seeds. Next year we sow only these large seeds, taking care to give them suitable soil and manure, and the result is found to be that the average size of the seeds is larger than in the first crop and that the largest seeds are now somewhat larger and more numerous. Again sowing these, we obtain a further slight increase of size, and in a very few years we obtain a greatly improved race, which will always produce larger seeds than the unimproved race, even if cultivated without any special care. In this way all our fine sorts of vegetables, fruits and flowers have been obtained, all of our choice breeds of cattle or of poultry, our wonderful race-horses and our endless varieties of dogs. It is a very common but mistaken idea that this improvement is due to crossing and feeding in the case of animals, and to improved cultivation in the case of plants. Crossing is occasionally used in order to obtain a combination of qualities found in two distinct breeds, and also because it is found to increase the constitutional vigor; but every breed possessing any exceptional quality is the result of the selection of variations occurring year after year and accumulated in the manner just described. Purity of breed, with repeated selection of the best varieties of that breed, is the foundation of all improvement in our domestic animals and cultivated plants.

"The experience of breeders and cultivators proves that variation is the rule instead of the exception, and that it occurs, more or less, in almost every direction. This is shown by the fact that different species of plants and animals have required different kinds of modifications to adapt them to our use, and we have never failed to meet with variation in that particular direction, so as to enable us to accumulate it and so to produce ultimately a large amount of change in the required direction. Our gardens furnish us with numberless examples of this property of plants. In the cabbage and lettuce we have found variation in the size and mode of growth of the leaf, enabling us to produce by selection the almost innumerable varieties, some with solid heads of foliage quite unlike any plant in a state of nature, others with curiously wrinkled leaves like the savoy, others of deep purple color used for pickling. From the very same species as the cabbage have arisen the broccoli and cauliflower, in which the leaves have undergone little alteration, while the branching heads of flowers grow into a compact mass forming one of our most delicate vegetables.

"The most remarkable varieties are afforded by the apple, and some account of these will be given as illustrating the effects of slight variations accumulated by selection. All our apples are known to have descended from the common crab of our hedges, and from this at least a thousand distinct varieties have been produced. These differ greatly in the size and form of the fruit, in its color, and in the texture of the skin. They further differ in the time of ripening, in their flavor, and in their keeping properties; but apple-trees also differ in many other ways.

"Coming now to our domesticated animals, we find still more extraordinary cases; and it appears as if any special quality or modification in an animal can be obtained if we only breed it in sufficient quantity, watch carefully, for the required variations, and carry on selection with patience and skill for a sufficiently long period. Thus, in sheep we have enormously increased the wool, and have obtained the power of rapidly forming flesh and fat; in cows we have increased the production of milk; in horses we have obtained strength, endurance, or speed, and have greatly modified size, form, and color; in poultry we have secured various colors of plumage, increase of size, and almost perpetual egg-laying; and in dogs and pigeons marvelous changes have been effected."

The facts of individual variation from the viewpoint of a prominent American botanist will supplement the statements of Darwin and Wallace. Professor L. H. Bailey based his lectures on "Plant Breeding" on the universal difference in nature. He says: "No two living things are exact counterparts, for no two are born into exactly the same conditions and experiences. Every living object has individuality; that is, there is something about it which enables the acute observer to distinguish it from all other objects, even of the same class or species. Every plant in a row of lettuce is different from every other plant, and the gardener, when transplanting them selects out, almost unconsciously, some plants which please him and others which do not. If one were to make the effort, he would find that it is possible to distinguish differences between every two spears of grass in a meadow or every two heads of wheat in a grain-field.

"All this is equivalent to saying that plants are infinitely variable. The ultimate causes of all this variation are beyond the purpose of the present discussion, but it must be evident to the reflective mind that these differences are the means of adapting the innumerable individuals to every little difference or advantage in the environment in which they live.

"If no two plants are anywhere alike, then it is not strange if now and then some departure, more marked than common, is named and becomes a garden variety. We have been taught to feel that plants are essentially stable and inelastic, and that any departure from the type is an exception, and calls for immediate explanation. The fact is, however, that plants are essentially unstable and plastic, and that variation between the individuals must everywhere be expected. This erroneous notion of the stability of organisms comes of our habit of studying what we call species. We set for ourselves a type of plant or animal and group about it all those individuals which are more like this type than they are like any other, and this group we name a species. Nowadays, the species is regarded as nothing more than convenient and arbitrary expression for classifying our knowledge of the forms of life, but the older naturalists conceived that the species is the real entity or unit in nature, and we have not yet wholly outgrown the habit of mind which was born of that fallacy.

"Nature knows nothing about species; she is concerned with the individual, the ultimate unit. This individual she molds and fits into the chinks of environment, and each individual tends to become the more unlike its birthmates the more the environments of the various individuals are unlike. I would impress upon you, therefore, the importance of the individual plant, rather than the importance of the species; for thereby we put ourselves as nearly as possible in a sympathetic attitude with Nature, and, resting upon the ultimate object of her concern, we are able to understand what may be conceived to be her motive in working out the problems of life."

It should be noted that Darwin did not give much attention to the causes of variation. He simply gathered together the data to show that organisms are highly variable. Given the facts of the high variability of individuals of all plants and animals, and the intense struggle for existence, how will this struggle act in regard to variation? Can the principle of selection, which is seen to be so potent in the hands of man in artificial selection, apply to organisms in a state of nature? These are essentially the questions which Darwin asked, and his own answer, now become a classic in science, is still the most satisfactory.

"I think we shall see," he says, "that it (the principle of selection) can act most efficiently. Let the endless number of slight variations and individual differences occurring in our domestic productions, and in a lesser degree in those under nature, be borne in mind; as well as the strength of the hereditary tendency. Under domestication, it may be truly said that the whole organization becomes in some degree plastic. But the variability, which we almost universally meet with in our domestic productions, is not directly produced, as Hooker and Asa Gray have well remarked by man; he can neither originate varieties nor prevent their occurrence; he can only preserve and accumulate such as do occur. Unintentionally he exposes organic beings to new and changing conditions of life, and variability ensues; but similar changes of conditions might and do occur under nature. Let it also be borne in mind how infinitely complex and close-fitting are the mutual relations of all organic beings to each other and to their physical conditions of life; and consequently what infinitely varied diversities of structure might be of use to each being under changing conditions of life.

"Can it, then, be thought improbable, seeing that variations useful to man have undoubtedly occurred, that other variations useful in some way to each being in the great and complex battle of life should occur in the course of many successive generations? If such do occur, can we doubt (remembering that many more individuals are born than can possibly survive) that individuals having any advantage, however slight, over others, would have the best chance of surviving and of procreating their kind? On the other hand, we may feel sure that any variation in the least degree injurious would be rightly destroyed. This preservation of favorable individual differences and variations, and the destruction of those which are injurious, I have called Natural Selection, or the Survival of the Fittest. Variations neither useful nor injurious would not be affected by natural selection, and would be left either a fluctuating element, as perhaps we see in certain polymorphic species, or would ultimately become fixed, owing to the nature of the organism and the nature of the conditions.

"We have good reason to believe that changes in the conditions of life give a tendency to increased variability; and this would manifestly be favorable to natural selection, by affording a better chance of the occurrence of profitable variations. Unless such occur, natural selection can do nothing. Under the term of 'variations' it must never be forgotten that mere individual differences are included. As man can produce a great result with his domestic animals and plants by adding up in any given direction individual differences, so could natural selection, but far more easily, from having incomparably longer time for action.

"Nor do I believe that any great physical change, as of climate, or any unusual degree of isolation to check immigration, is necessary in order that new and unoccupied places should be left, for natural selection to fill up by improving some of the varying inhabitants. For as all the inhabitants of each country are struggling together with nicely balanced forces, extremely slight modifications in the structure or habits of one species would often give it an advantage over others; and still further modifications of the same kind would often still further increase the advantage, as long as the species continued under the same conditions of life and profited by similar means of substance and defense.

"As man can produce, and certainly has produced, a great result by his methodical and unconscious means of selection, what may not natural selection effect? Man can act only on external and visible characters. Nature, if I may be allowed to personify the natural preservation or survival of the fittest, cares nothing for appearances, except in so far as they are useful to any being. She can act on every internal organ, on every shade of constitutional difference, on the whole machinery of life. Man selects only for his own good: Nature only for that of the being which she tends. Every selected character is fully exercised by her, as is implied by the fact of their selection. Man keeps the natives of many climates in the same country; he seldom exercises each selected character in some peculiar and fitting manner; he feeds a long and a short beaked pigeon on the same food; he does not exercise a long-backed or long-legged quadruped in any peculiar manner; he exposes sheep with long and short wool to the same climate. He does not allow the most vigorous males to struggle for the females. He does not rigidly destroy all inferior animals, but protects during each varying season as far as lies in his power, all his productions. He often begins his selection by some half-monstrous form; or at least by some modification prominent enough to catch the eye or to be plainly useful to him. Under nature, the slightest differences of structure or constitution may well turn the nicely balanced scale in the struggle for life, and so be preserved. How fleeting are the wishes and efforts of man! how short his time! and consequently how poor will be his results, compared with those accumulated by Nature during whole geological periods! Can we wonder, then, that Natures's productions should be far 'truer' in character than man's productions; that they should be infinitely better adapted to the most complex conditions of life, and should plainly bear the stamp of far higher workmanship?

"It may metaphorically be said that natural selection is daily and hourly scrutinizing, throughout the world, the slightest variations; rejecting those that are bad, preserving and adding up all that are good; silently and insensibly working, whenever and wherever opportunity offers, at the improvement of each organic being in relation to its organic and inorganic conditions of life. We see nothing of these slow changes in progress until the hand of time has marked the lapse of ages, and then so imperfect is our view into long-past geological ages that we see only that the forms of life are now different from what they formerly were.

"In order that any great amount of modification should be affected in a species, a variety when once formed must again, perhaps after a long interval of time, vary or present individual differences of the same favorable nature as before; and these must be again preserved, and so onward step by step. Seeing that individual differences of the same kind perpetually recur, this can hardly be considered as an unwarrantable assumption. But whether it is true, we can judge only by seeing how far the hypothesis accords with and explains the general phenomena of nature. On the other hand, the ordinary belief that the amount of possible variation is a strictly limited quantity is likewise a simple assumption.

"Altho natural selection can act only through and for the good of each being, yet characters and structures, which we are apt to consider as of very trifling importance, may thus be acted on. When we see leaf-eating insects green, and bark-feeders mottled-gray, the alpine ptarmigan white in winter, the red grouse the color of heather, we must believe that these tints are of service to these birds and insects in preserving them from danger. Grouse, if not destroyed at some period of their lives, would increase in countless numbers; they are known to suffer largely from birds of prey; and hawks are guided by eyesight to their prey—so much so that on parts of the Continent persons are warned not to keep white pigeons, as being the most liable to destruction. Hence natural selection might be effective in giving the proper color to each kind of grouse, and in keeping that color, when once required, true and constant. Nor ought we to think that the occasional destruction of an animal of any particular color would produce little effect; we should remember how essential it is in a flock of white sheep to destroy a lamb with the faintest trace of black.

"In looking at many small points of difference between species, which, as far as our ignorance permits us to judge, seem quite unimportant, we must not forget that climate, food, etc., have no doubt produced some direct effect. It is also necessary to bear in mind that owing to the law of correlation, when one part varies, and the variations are accumulated through natural selection, other modifications, often of the most unexpected nature, will ensue.

"As we see that those variations which, under domestication, appear at any particular period of life, tend to reappear in the offspring at the same period—for instance, in the shape, size and flavor of the seeds of the many varieties of our culinary and agricultural plants; in the caterpillar and cocoon stages of the varieties of the silk-worm; in the eggs of poultry, and in the color of the down of their chickens; in the horns of our sheep and cattle when nearly adult—so in a state of nature natural selection will be enabled to act on and modify organic beings at any age, by the accumulation of variations profitable at that age, and by their inheritance at a corresponding age.

"If it profit a plant to have its seeds more and more widely disseminated by the wind, I can see no greater difficulty in this being effected through natural selection than in the cotton planter increasing and improving by selection the down in the pods on his cotton-trees. Natural selection may modify and adapt the larva of an insect to a score of contingencies wholly different from those which concern the mature insect; and these modifications may effect, through correlation, the structure of the adult. So, conversely, modifications in the adult may affect the structure of the larva; but in all cases natural selection will ensure that they shall not be injurious; for if they were so, the species would become extinct.

"Natural selection will modify the structure of the young in relation to the parent, and of the parent in relation to the young. In social animals it will adapt the structure of each individual for the benefit of the whole community, if the community profits by the selected change. What natural selection cannot do is to modify the structure of one species, without giving it any advantage, for the good of another species; and tho statements to this effect may be found in works of natural history, I cannot find one case which will bear investigation. A structure used only once in an animal's life, if of high importance to it, might be modified to any extent by natural selection; for instance, the great jaws possessed by certain insects, used exclusively for opening the cocoon; or the hard tip to the beak of unhatched birds, used for breaking the egg.

"It may be well to remark that with all beings there must be much fortuitous destruction, which can have little or no influence on the course of natural selection. For instance, a vast number of eggs or seeds are annually devoured, and these could be modified through natural selection only if they varied in some manner which protected them from their enemies. Yet many of these eggs or seeds would, perhaps, if not destroyed, have yielded individuals better adapted to their conditions of life than any of those which happened to survive. So again, a vast number of mature animals and plants, whether or not they be the best adapted to their conditions, must be annually destroyed by accidental causes, which would not be in the least degree mitigated by certain changes of structure or constitution which would in other ways be beneficial to the species.

"But let the destruction of the adults be ever so heavy, if the number which can exist in any district be not wholly kept down by such causes—or again, let the destruction of eggs or seeds be so great that only a hundredth or a thousandth part are developed—yet of those which do survive the best adapted individuals, supposing that there is any variability in a favorable direction, will tend to propagate their kind in larger numbers than the less well adapted. If the numbers be wholly kept down by the causes just indicated, as will often have been the case, natural selection will be powerless in certain beneficial directions; but this is no valid objection to its efficiency at other times and in other ways, for we are far from having any reason to suppose that many species ever undergo modification and improvement at the same time in the same area."

In concluding this sketch of Darwin's Natural Selection theory it should be noted that Darwin believed natural selection to be the most important, but not the sole, factor in producing new forms of organisms. His later followers, especially of the Weismann school, have held natural selection to be the all-sufficient factor of development. It will be necessary to return to this in discussing modern criticisms of Darwinism. Summarizing the essential points in the natural selection theory, Jordan and Kellogg say that: "Of all the various factors of organic development, the one which has been most relied on as the great determining agent is that called Natural Selection, the survival of the individuals best fitted for the conditions of life, with the inheritance of those species-forming adaptations in which fitness lies. The primal initiative is not in natural selection, but in variation—germinal and individual. This may be slight variation (fluctuation) or large deviation (saltation), but in any case, all difference in species or race must first be individual. The impulse to change, once arisen, is continued through heredity. From natural selection arises the choice among different lines of descent, the adaptive tending to exclude the nonadaptive, while traits which are neither helpful nor hurtful, but simply indifferent, may be borne along by the current of adaptive characters. Finally, separation or isolation tends to preserve a special line of heredity from being merged in the mass which constitutes the parent stock or species. Without individual variation no change could take place; all organisms would be identical in structure."

Altho the Darwinian theory has been subject to no popularly recognized attack during the last quarter of a century, nevertheless there has been accumulating a mass of criticism of it. Only a sketch of some of the leading criticisms can be presented. These will be taken in large measure from Kellogg's "Darwinism To-day."

"Among the critics of the selection theories," he says, "we must note two groups, differing in the character of their criticism more in degree than in kind, perhaps, but still importantly differing. One group denies in toto any effectiveness or capacity for species-forming on the part of natural selection, while the other group, a larger one, sees in natural selection an effective factor in directing or controlling the general course of descent, holding it to adaptive lines, but denies it outright any such 'Allmacht' of species control as the more eager selectionists, the so-called neo-Darwinians or Weismannians, credit it with. This larger group of critics sees in natural selection an evolutionary factor capable of initiating nothing, dependent wholly for any effectiveness on some primary factor or factors controlling the origin and direction of variation, but wholly capable of extinguishing all unadapted, unfit lines of development, and in this way of exercising decisive final control over the general course of descent—*i.e.*, organic evolution.

"The general impression left on one after a considerable course of anti-Darwinian reading is that there is a very real and effective amount of destructive criticism for Darwinians to meet; and at the same time a curious paucity of satisfactory or at all convincing substitutionary theory offered by the anti-Darwinians to replace that which they are attempting to dethrone. The situation illustrates admirably the varying worth of a few facts. A few stubborn facts of the wrong complexion are fatal things for a theory; they are immensely effective offensive weapons. But these same few facts make a pitiable showing when they are called on to support a theory of their own.

"It was exactly the greatest part of Darwin's greatness, it seems to me, that he launched his theory only after making the most remarkable collection of facts yet gathered together in biological science by any one man. Testing his theory by applying to it successively fact after fact, group after group, and category after category of facts, he convinced himself of the theory's consonance with all this vast array of observed biological actuality.

"Compare the grounding of any of the now offered replacing theories with the preparation and founding of Darwinism. In 1864 von Kölliker, a great biologist, convinced of the incapacity of natural selection to do the work assigned it by its founders and friends, suggested a theory of the origin of species by considerable leaps; in 1899 Korschinsky, on the basis of some few personal observations and the compiling of some others, definitely formulated a theory of species-forming by sudden considerable variations, namely, mutations; in 1901 and 1903 appeared the two volumes of De Vries's 'Die Mutations-theorie,' in which are revealed the results of long years of careful observation, in truly Darwinian manner, directed toward the testing and better grounding of this mutations-theory of species-origin. The results are: out of many plant species studied a few show at certain times in the course of numerous generations a behavior in accordance with the demands of a theory of species-forming by sudden definitive modification; that is, species-forming by mutations.

"The mutations-theory thus launched is offered as a substitute for the natural selection theory obviously weakening under the fire of modern scientific criticism. But however effective De Vries's facts are in proving the possibility of the occurrence of other variations than those fortuitous ones occurring in continuous series from mean to opposite extremes which Darwin recognized as the basis of species-forming, and however effective they are in proving the actual production of three or six or ten species by mutation, and however effective in both these capacities they are as weapons of attack on the dominance of the Darwinian theory of species-making, how really inadequate they are to serve as the basis of a great all-answering theory explaining in a causo-mechanical way the facts of descent, or even the primary facts of general species-forming.

"The natural selection theory, as an all-sufficient explanation of adaptation and species-forming, has always had a weakness at its base; it depends absolutely, of course, on the preexistence of variations, but it itself has no influence whatever on the origin or control of these variations to give birth to other individuals. Now one of the chief problems in biology is exactly that of the origin, the causes, and the primary control of these congenital variations.

"Three principal explanations, no one of them experimentally proved or even fairly tested as yet, have been given of this actually occurring congenital variation, viz., (1) that there exists in the germ-plasm an inherent tendency or capacity to vary so that there is inevitable variation in all individuals produced from germ-plasm, this variation being wholly fortuitous and fluctuating according to some (the belief of Darwin and his followers), or, according to others, this variation following certain fixed or determinate lines (determinate variation, orthogenetic variation, etc.); (2) that amphimixis—*i.e.*, bi-parental parentage—is the principal cause of variation, it seeming logical to presume that individuals produced from germ-cells derived from the fusion of germ-plasm coming from two individuals more or less unlike would differ slightly from either of the parental individuals; and (3) that congenital variation is due to the influence of the ever-varying environment of the germ-cell producing individuals.

"The objections to any one of these theories may be very pertinent, as when one says regarding the first that calling a thing 'inherent' is not clearing up in any degree a phenomenon for which we are demanding a causo-mechanical explanation; or of the second, that it has been proved that individuals produced parthenogenetically—that is, from an unmated mother—vary, and in some cases vary more than do other individuals of the same species produced by amphimixis; or of the third, that as far as our study of the actual processes and mechanism of the production of germ-cells and of embryos has gone, we have found no apparent means whereby this influence of the ambient medium can be successfully impressed on the germ-plasm. But however pertinent the objections to the why of variation may be, they do not in any way invalidate the fact that variations do continuously and inevitably occur in all individuals, and that while many of these variations are recognizably such as have been impressed on the individual during its personal development as immediate results of varying temperature, amount or kind of food, degree of humidity, etc., to which it may be exposed in its young life, others seem wholly inexplicable on a basis of varying individual environment, and are certainly due to some antenatal influence acting on the germ-plasm from which the embryo is derived.

"Now, the natural selection theory, in its Darwinian and neo-Darwinian form, presupposes fortuitously occurring congenital variations of practically infinite variety in all parts of all organisms. Actual observation shows that all parts of all organisms do vary, and that they vary congenitally; that is, independently of any immediate influence during development exercised from without by environmental conditions, as well as in response to these environmental influences, and finally, that in many cases this variation is fortuitous—that is, that it occurs according to the laws of chance.

"The industrious statistical study of variations, including the tabulation of the variation condition in long series of individuals of the same species or race, and the mathematical formulation of this variation condition, have shown that in many specific cases, studied in numerous kinds of animal and plant forms, the character of the variation in any particular character may be truly represented (with close approximation) by the mathematical expression and curve which would exactly define the condition in which the variation would exist if it actually followed the law of error. It is these continuous series of slight variations, these variously called fluctuating, individual, or Darwinian variations, occurring in all organisms at all times, and often following in their occurrence the laws of chance, on which Darwin's theory of species-forming by natural selection is based.

"But this same industrious statistical and quantitative study of variation which has proved that some variations do occur regularly, fluctuating around a mean or mode, has shown, as well, that in many cases the variations distinctly tend to heap up on one side or the other of the mean; that is, that they tend to occur along certain lines or toward certain directions rather than uniformly out in all directions. Also it is true—and this has, of course, been long known—that by no means all variations are so slight nor in such perfectly gradatory or continuous series as is true of the gradatory Darwinian variations. 'Sports' have been known to breeders of plants and animals ever since plant and animal breeding began. Bateson has filled a large book with records of 'discontinuous variations' in animals; variations, that is, of large size and not occurring as members of continuous gradatory series. So that biologists are acquainted with many cases of variation that seem to be of a kind, or to exhibit a tendency to institute special directions of development, and thus not to be of the simple, nonimitating, inert character of the fortuitous, slight, fluctuating variations, among which natural selection is presumed to choose those that are to become the beginnings of new lines of modification and descent. Many biologists believe firmly that variations occur in many special cases, if not in most cases, only along certain special lines. Paleontologists believe, practically as a united body, that variation has followed fixed lines through the ages; that there has been no such unrestricted and utterly free play of variational vagary as the Darwinian natural selection theory presupposes.

"Now it is at least obvious that natural selection is absolutely limited in its work to the material furnished by variation, so that if variation occurs in any cases along certain determinate lines, selection can do no more than make use of these lines. Indeed, if variation can occur persistently along determinate lines, natural selection's function in controlling development in such cases is limited to the police power of restricting or inhibiting further development along any one or more of these lines which are of a disadvantageous character; that is, a character which handicaps or destroys the efficiency of its members in the struggle for life. The question in many men's mouths to-day is, Why may not variation be the actual determinant factor in species-forming, in descent? It actually is, respond many biologists and paleontologists. Even Darwin believed such determinate variation to occur, as is indicated by repeated statements in the 'Origin of Species.'"

This problem of the existence or non-existence of determinate variations is one of the most important matters in connection with the whole great problem of descent; that is, of evolution. It is the basic problem of development, for it is the problem of beginnings. Selection, isolation, and the like factors are conditions of species-forming; variation is a prerequisite. True variation must have its causes, and these causes are to be determined before an actual causo-mechanical explanation of evolution can ever be found. But the determination of the relation of variation to species-forming is certainly the first step now necessary in our search for the basic factors, the real first cause of species change.

Space will not permit analysis of the general lines of objections raised in the foregoing. These objections have led many biologists to the totally ante-Darwinian position that the struggle for existence and the corresponding selection of the fit are not factors of development. But perhaps the majority of biologists who recognize the objections cited are inclined to belief in natural selection as the great "conserving factor of development" while allowing that it does not create new forms. To quote from T. H. Morgan, ". . . the theory of natural selection has nothing to do with the origin of the species, but with the survival of already formed species. Not selection of the fittest individuals, but the survival of the sufficiently fit species."

In summarizing the present-day standing of the Darwinian theory, Kellogg says: "I think I speak fairly in saying that the believers and defenders of the natural selection theory to-day admit in large measure the validity of those criticisms which are directed at the incapacity of Darwinism, in its long familiar form, to account for the development of variations and modifications up to the advantageous or disadvantageous stage. They concede, or at least most of them, including Weismann, do, the force of the criticism that the assumption of the occurrence of the right variations at the right time is a necessity for the development by selection of many, if not most, specializations of qualitative and coadaptive character, which assumption in turn demands an explanation of causes anterior to selection.

"And finally, most selectionists concede that selection cannot make new species by relying on the extremes of series of fluctuating or Darwinian variations, because of the inevitable extinguishing or swamping of these extreme variations by interbreeding with the far more abundant average or model individuals of the species."

Making such concessions, it is necessary to recognize that there are factors of development other than natural selection, and these require separate treatment. At the same time, before entering on the question of sexual selection, it seems necessary to state that this theory has lately been supplanted by its newer form that secondary sex characters are resultants from hormones sent into the blood by sex organs. Sex determination is still under discussion, but the balance of evidence favors the view that the chromosomes are the carriers of hereditary qualities and that the accessory in some way determines sex.

CHAPTER XIII

SELECTION—SEXUAL SELECTION

In building up the theory of Natural Selection Darwin found that while this theory was sufficient to explain the useful in organic structures it did not sufficiently explain "that class of phenomena which go to constitute the Beautiful." Darwin, therefore, suggested an auxiliary theory to give a scientific explanation to these widespread phenomena. To quote Romanes: "Just as by his theory of natural selection he sought to explain the major fact of utility, so did he endeavor to explain the minor fact of beauty, by a theory of what he termed Sexual Selection." Kellogg's exposition of this theory has been partly followed in the following account.

Every zoologist is familiar with the striking differences between the male and female individual of a single species. The reader will recall the feathers of many male birds which are in striking contrast to the sober plumage of their mates. These differences in size, color, general appearances, and various specific structural details in head, trunk, wings, feet, plumage, etc., are over and beyond those primary radical differences existing in all species in which the two sexes are differentiated. Some of these differences may, however, have obvious relation to the primary differences, in that they may be connected immediately with the act of pairing or with the work of rearing the young. The presence in male insects of complexly developed holding organs, and in female mammals of milk glands, exemplifies differences of this category. A great many sexual differences, however, have no such obvious direct relation to the function of producing and rearing the young.

Such are the metallic purple and bronze colors of the male grackles compared with the dull brown of the females; the long tails and brilliant coloration of the male pheasants, the great spreading, patterned tail of the peacock, the larger size or the winglessness of many female insects, etc. All these differences between male and female of the same species of animals, beyond or in addition to the differences between the actual primary reproductive organs, are known as secondary sexual differences, or the characters themselves, which may be characteristics of physiology and habit, as well as the more familiar ones of structure, are called secondary sexual characters. The layman may not readily appreciate the abundance and the great variety of these characters, but it is a fact that almost all species of animals, excepting those in the lower invertebrate branches, show them, and if one will try to recall the aspect of the two sexes in one after another of the species of animals with which one is familiar, mammals, birds, insects, etc., one will begin to realize how widespread and significant are these secondary sexual characters.

Many of these secondary sexual characters have uses which are of a kind directly helpful in the struggle for existence, as the strong antlers of the stags, useful in defense against attacking enemies; the brood sacs of the kangaroos and opossum, useful in caring for their helpless young; the milk glands and teats of all female mammals, and the protective colors and patterns of many insects and birds. But others of these secondary sexual characters are either of a kind apparently useless in the struggle for life, or even of a kind actually harmful.

Of apparent harmfulness are the conspicuous staring colors of many male birds, the long dangling plumes, the weighty crests and heavy, dragging tails of others; all these parts also usually being dangerously, conspicuously colored. The lively loud song of many male birds, and the dancing and leaping of numerous male spiders and some male birds must also involve some danger to the performers by attracting the attention of their enemies. In fact, most of those secondary sexual characters that are classified under the general head of "exciting organs" are apparently of a sort that should be actually disadvantageous in the struggle for existence. They are of a character tending to make their possessors conspicuous, and thus readily perceived by their carnivorous enemies. How is to be explained the existence of so many and such highly developed structural and physiological characters of this kind, a condition that seems to stand in direct opposition to the theory of natural selection? Darwin's answer to this question is contained in his theory of sexual selection.

This theory, in few words, is that there is practically a competition or struggle for mating, and that those males are successful in this struggle which are the strongest and best equipped for battle among themselves, or which are most acceptable, by reason of ornament or other attractiveness, to the females. In the former case, mating with a certain female depends upon overcoming in fight the other suitors, the female being the passive reward of the victor; in the second case the female is presumed to exercise a choice, this choice depending upon the attractiveness of the male. The actual fighting among males, and the winning of the females by the victor, are observed facts in the life of numerous animal species. But a special sexual selection theory is hardly necessary to explain the development of the fighting equipment—antlers, spurs, claws, etc.

This fighting array of the male is simply a special phase of the already recognized intra-specific struggle; it is not a fight for room or food, but for the chance to mate. But this chance often depends on the issue of a life-and-death struggle. Natural selection would thus account for the development of the weapons for this struggle.

For the development, however, of such secondary sexual characters as ornament and song, and special odors, and "love-dancing," the natural selection theory can in no way account; the theory of sexual selection was the logical and necessary auxiliary theory, and when first proposed by Darwin met with quick and wide acceptance. Wallace, in particular, took up the theory and applied it to explain many cases of remarkable plumage and pattern development among birds. Later, as he analyzed more carefully his cases, and those proposed by others, he became doubtful, and finally wholly skeptical of the theory.

A few extracts from the "Origin of Species" will present the theory in Darwin's own words. "This form of selection," he explains, "depends, not on a struggle for existence in relation to other organic beings, or to external conditions, but on a struggle between the individuals of one sex, generally the males, for the possession of the other sex. The result is not death to the unsuccessful competitor, but few or no offspring. Sexual selection is, therefore, less rigorous than natural selection. Generally, the most vigorous males, those which are best fitted for their places in nature, will leave most progeny. But in many cases victory depends not so much on general vigor as on having special weapons, confined to the male sex. A hornless stag or spurless cock would have a poor chance of leaving numerous offspring. Sexual selection, by always allowing the victor to breed, might surely give indomitable courage, length to the spur, and strength to strike in the spurred leg, in nearly the same manner as does the brutal cockfighter by the careful selection of his best cocks.

"Among birds the contest is often of a peaceful character. All those who have attended to the subject believe that there is the severest rivalry between the males of many species to attract, by singing, the females. The rock-thrush of Guiana, birds of paradise, and some others, congregate; and successive males display with the most elaborate care, and show off in the best manner, their gorgeous plumage; they likewise perform strange antics before the females, which, standing by as spectators, at last choose the most attractive partner. If man can in a short time give beauty and an elegant carriage to his bantams, according to his standard of beauty, I can see no good reason to doubt that female birds, by selecting, during thousands of generations, the most melodious or beautiful males, according to their standard of beauty, might produce a marked effect."

Many difficulties in the way of the application of this theory have been advanced in recent years as a result of experimental work and more widespread observation. Morgan lists twenty such objections. Space will allow mention of only a few of the most important criticisms of the theory. These are outlined by Kellogg essentially as follows.

The theory can be applied only to a species in which the males are markedly more numerous than the females, or in which the males are polygamous. In other cases there will be a female for each male, whether he be ornamented or not; and the unornamented males can leave as many progeny as the ornamented ones, which would prevent any cumulation of ornamental variations by selection. As a matter of fact, in a majority of animal species, at least among the vertebrates, males and females exist in approximately equal numbers. Observation shows that in most species the female is wholly passive in the matter of pairing, accepting the first male that offers.

"Ornamental colors," moreover, as Kellogg points out, "are as often a characteristic of males of kinds of animals in which there is no real pairing as among those which pair. How explain by sexual selection the remarkable colors in the breeding season of many fishes, in which the female never, perhaps, even sees the male which fertilizes her dropped eggs?

"Choice on a basis of ornament and attractiveness implies a high degree of esthetic development on the part of the females of animals for whose development in this line we have no (other) proof. Indeed, this choice demands esthetic recognition among animals to which we distinctly deny such a development, as the butterflies and other insects in which secondary sexual characters of color, etc., are abundant and conspicuous. Similarly with practically all invertebrate animals. Further, in those groups of higher animals where esthetic choice may be presumed possible we have repeated evidence that preferences vary with individuals. Besides, even if we may attribute fairly a certain amount of esthetic feeling to such animals as mammals and birds, is this feeling to be so keen as to lead the female to make choice among only slightly differing patterns of songs? Yet this assumption is necessary if the development of ornament and other attracting and exciting organs is to be explained by the selection and gradual cumulation through generations of slight fortuitously appearing fluctuating variations in the males.

"Even if the females do choose among the males on a basis of attractiveness, how are the characters of the more attractive males to become especially fostered and accumulated by selection? Do such males produce more offspring or more vigorous ones than the other males, which, tho rejected by the first females, find their mates among the females not already mated? Are we to attribute to the more ornamental males a particular vigor? If so, may not that very vigor be the cause of the extra-production of color or plumage or wattles, etc.?

"Darwin admits, in order to explain the beginnings of color and ornament development, a certain degree of difference between the male and female in regard to their reaction to environment influences. If so, may not these admitted differences be really sufficient to account for even a pretty high degree of difference in development of secondary sexual characters?

"The special display of colors, tufts, plumes, spreading tails, and other secondary sexual characters by the males at mating time is an observed fact; the 'dances' of cranes and storks, the serenades ot the song-birds, the evolutions of the male spiders, are all familiar phenomena in the mating season of these animals. And they probably do exercise an exciting effect on the females, and are probably actually displayed for this purpose. But does this in any way prove, or even give basis for, a reasonable presumption for belief in a discriminating and definite choice among the males on the part of the female? And it is this actual choosing which is the necessary basis for the theory of sexual selection.

"How explain the well-known cases of a similar extra-development of plumage in the nuptial season by both males and females, as in certain herons and other birds? And what of those cases in which it is the female that is the brighter-colored individual of the pair? To explain the latter case Darwin assumes that in these cases the males have done the selecting, but even this rather too easy removal of the situation postulated as a fundamental generalization of the theory does not explain the first of the questions in this paragraph. Do both sexes among the herons do selecting?"

To the objection that choice on the part of the female assumes her possession of an esthetic ideal and a power of selection in accordance with that ideal which is contrary to our knowledge of animal psychology, Lloyd Morgan answers that the choice is not one of deliberation but rather of impulse; it is simply a definite response to an adequate stimulus. "She accepts that mate which by his song or otherwise excites in sufficient degree the pairing impulse; if others fail to excite this impulse they are not accepted. It is a choice from impulse, not the result of deliberation; but it is a choice which is determined by the emotional meaning of the conscious situation. And it is the reiterated revival of the associated emotional elements which generates an impulse sufficiently strong to overcome her instinctive coyness and reluctance. It is a perceptual choice arising from impulse rather than an ideational choice due to motive and volition."

The final line of criticism is that experimental evidence is strongly opposed to the theory of sexual selection. Mayer, director of the

Tortugas laboratory of the Carnegie Institute, has proved by many careful experiments that the striking differences between the wings of male and female promethea moths, "Callosamia promethea," are absolutely without meaning in relation to sexual selection. The animals mate normally when painted, or after the wings have been cut off and others glued on in their place. Mayer tried to test the selective action of the female. The male promethea has blackish wings, while the females are reddish-brown. In accordance with the theory of sexual selection, the peculiar coloration of the male should be due to the selection of the dark-colored males, so that under this influence the males would become, in successive generations, darker until the present coloration has been attained. Mayer's own account of his experiments and conclusions to test the preferences and selective action of the females is as follows:

"In order to test this hypothesis I cut off the wings of a number of females, leaving only short stumps, from which all the scales were carefully brushed. Male wings were then neatly glued to the stumps, and thus the female presented the appearance of a male. Under these circumstances the males mated with the female quite as readily as they would have done under normal conditions.

"I then tried the experiment of gluing female wings upon the male. Here, again, the mating seemed to occur with normal frequency, and I was unable to detect that the females displayed any unusual aversion toward their effeminate-looking consorts.

"It is also interesting to note that normal males pay no attention to males with female wings.

"In another series of experiments the wings were cut entirely off of males and females and the scales brushed off their bodies, and yet these shabby males were readily accepted by normal females; nor could I see that normal males displayed any aversion to mating with wingless females."

Mayer's next experiments were directed to the end of determining if the males found the females by sight or by smell. By enclosing females in numerous jars variously arranged, and covered or uncovered, it was readily determinable that males never pay any attention to females enclosed in transparent jars so closed as to prevent the escape of any odors from the female, while to females enclosed in boxes, or wrapped in cotton so as to be invisible, but yet capable of giving odor off into the air, males came promptly and hovered about. To locate the organs of scent in the female, Mayer cut off abdomens from various females and then placed abdomens and abdomenless females at some little distance apart. Males came to the abdomens and not to the thorax plus wings, legs, and head parts. It was readily proved by experiments with males whose antennæ were covered with shellac, photographic paste, etc., that the sense of smell is seated in the antennæ. Males with antennæ covered with photographic paste did not find females, while the same males with this paste dissolved off did.

All this evidence showed quite clearly that it was odor rather than color which served to attract the males to the females. In lizards, too, in which sexual dimorphism is conspicuous, females showed no preference for particular patterns exhibited by the males in breeding coat. Many such experiments, with like results, seem to make the rejection of Darwin's theory of sexual selection necessary.

But if it is rejected other explanations of the origin of the secondary sexual characters are needed. Such theories have been advanced. Kellogg says of them that the theories proposed to account for secondary sexual characters "mostly rest on one or both of two principal assumptions; first, that the secondary sexual characters are produced as the result of the immediate stimulus (naturally different) of the sexually differing primary reproductive organs, this stimulus being usually considered to result from an internal secretion of the genital organs acting on certain tissues of the organism; and second, that the males, in most species, possess an excess of energy, which manifests itself in extra-growths, extra-development of pigment, plumage, etc., and that displays by the males of special movements, sound-making, etc., are direct effects of manifestations of sexual excitation."

It thus appears that the sexual selection theory, as a special application of natural selection, is far from being in good standing with present-day biologists. The truth is that most of the work recently done has been destructive, and there is, as yet, no satisfactory replacing theory.

CHAPTER XIV

FACTORS OTHER THAN SELECTION

THE most important question raised in biological science by Darwin's work is whether natural selection has been the sole, or but the main, cause of the descent of species, or organic development. Darwin's own answer to this question was quite distinct. "He stoutly resisted," says Romanes, "the doctrine that natural selection was to be regarded as the only cause of organic development."

In many parts of his works Darwin showed that he believed in the possibility of the inheritance of the effects of the use and disuse of organs, the Lamarckian factor. This view, and also the admission of still other factors, is clearly set forth in the first paragraph of the conclusion to the "Origin of Species." It has been said that a more strongly worded passage cannot be found in Darwin's writings, and that the last sentences present the only note of bitterness in all the thousands of pages Darwin wrote.

"I have now recapitulated," he says, "the facts and considerations which have thoroly convinced me that species have been modified during a long course of descent. This has been affected chiefly through the natural selection of numerous successive, slight, favorable variations, aided in an important manner by the inherited effects of the use and disuse of parts, and in an unimportant manner, that is, in relation to adaptive structures, whether past or present, by the direct action of external conditions, and by variations which seem to us, in our ignorance, to arise spontaneously. It appears that I formerly underrated the frequency and value of these latter forms of variation, as leading to permanent modifications of structure independently of natural selection.

"But as my conclusions have lately been much misrepresented, and it has been stated that I attribute the modification of species exclusively to natural selection, I may be permitted to remark that in the first edition of this work, and subsequently, I placed in a most conspicuous position—namely, at the close of the Introduction—the following words: 'I am convinced that natural selection has been the main, but not the exclusive, means of modification.' This has been of no avail. Great is the power of steady misrepresentation; but the history of science shows that, fortunately, this power does not long endure."

While Darwin thus admitted the possibility of other factors of evolution, Alfred Russel Wallace, the co-originator of the natural selection theory, has believed natural selection to be the all-sufficient factor. Romanes has thus contrasted the views of Darwin and Wallace:

According to Darwin, Natural Selection has been the main means of modification, not excepting the case of Man. (a) Therefore it is a question of evidence whether the Lamarckian factors have cooperated. (b) Neither all species, nor, a fortiori, all specific characters, have been due to natural selection. (c) Thus the principle of Utility is not of universal application, even where species are concerned. (d) Thus, also, the suggestion as to Sexual Selection, or any other supplementary cause of modification, may be entertained; and, as in the case of the Lamarckian factors, it is a question of evidence, whether, or how far, they have cooperated. (e) No detriment arises to the theory of natural selection as a theory of the origin of species by entertaining the possibility, or the probability, of supplementary factors. (f) Cross-sterility in species cannot possibly be due to natural selection.

According to Wallace, Natural Selection has been the sole means of modification, excepting in the case of Man. (a) Therefore it is antecedently impossible that the Lamarckian factors can have cooperated. (b) Not only all species, but all specific characters, necessarily have been due to natural selection. (c) Thus the principle of Utility must necessarily be of universal application, where species are concerned. (d) Thus, also, the suggestion as to Sexual Selection, or of any other supplementary cause of modification, must be ruled out; and, as in the case of the Lamarckian factors, their cooperation deemed impossible. (e) The possibility—and, a fortiori, the probability—of any supplementary factors cannot be entertained without serious detriment to the theory of natural selection, as a theory of the origin of species. (f) Cross-sterility in species is probably due to natural selection.

This comparison makes it evident that the Darwinism of Darwin is natural selection plus other factors, while the Darwinism of Wallace is natural selection alone as the cause of evolution. In late years this view of Wallace's has been highly developed by Weismann and his followers, who have argued for the all-sufficiency of natural selection, and have especially opposed other factors which Darwin admitted might have aided natural selection. This view of Wallace and Weismann should be called "Neo-Darwinism" or "Ultra-Darwinism." In discussing the criticisms of natural selection it has been shown that there are serious difficulties in the way of universal application of neo-Darwinism. For this reason even Weismann has been forced to modify his views.

Most prominent of the theories of the factors of evolution which have rivaled natural selection is that put forth, before Darwin's work, by Lamarck (1744-1829). Lamarck's theory did not attract much attention during his lifetime, but since Darwin's time Lamarckism has become well known. The Lamarckian theory is commonly referred to as the theory of use and disuse and the direct action of the environment in modifying organs. Moreover, it holds that characteristics acquired during the lifetime of an individual are transmissible by heredity.

The Lamarckian view, as given by Osborn, is formulated in the four well-known propositions following:

(1) Life, by its internal forces, tends continually to increase the volume of every body that possesses it, as well as to increase the size of all the parts of the body up to a limit which it brings about.

(2) The production of a new organ or part results from a new need or want, which continues to be felt, and from the new movement which this need initiates and causes to continue. (This is the physical factor in his theory, which Cope later has termed Archesthetism.)

(3) The development of organs, and their force or power of action, are always in direct relation to the employment of these organs. (At another point he expands this into two sub-laws: "In every animal which has not passed the term of its development, the more frequent and sustained employment of each organ strengthens little by little this organ, develops it, increases it in size, and gives it a power proportioned to the length of its employment; whereas the constant lack of use of the same organ insensibly weakens it, deteriorates it, progressively diminishes its powers, and ends by causing it to disappear." This is now known as the Law of Use and Disuse, or Kinetogenesis.)

(4) All that has been acquired or altered in the organization of individuals during their life is preserved by generation and transmitted to new individuals which proceed from those which have undergone these changes.

The greatest weakness in the Lamarckian theory is the assumption of the inheritance of acquired characters; this Lamarck took for granted, and did not try to demonstrate. As Kellogg has well said:

"That an animal in its lifetime, and especially during its immature life, can effect very considerable changes in some of its body-parts by special use or disuse of these parts, or that certain parts may be modified through the influence of external stimuli, is familiar knowledge. The heart and lungs can be enlarged by special use; in short, almost any of the organs of the body which are actively used can be modified either by unusual or extra use, or by unusual lack of use. Now this use is, in Nature, almost always of the character of a better aiding in successful living; that is, it is adaptive use. If such betterment of organs and their functions acquired by individuals could be inherited by their young, it is obvious that general adaptations of this sort could be rapidly developed in the course of generations, and new species, new, that is, because of the adaptive changes thus effected, be formed. This is the essential thought in Lamarck's theory of the method of adaptation and species-forming.

"The essential principle of Lamarckism is an orthogenic evolutionary progress toward better and finer adaptation and adjustment resulting from the inherited effects of actual use, disuse, and functional stimulation of parts. It is a great thought and a clear one, and only needs the proof of the actuality of the inheritance of individually acquired characters to make it one of the principal casual explanations of adaptation and species change.

"However, it is exactly this proof that is wanting. At any rate, proof of the character and extent necessary to convince all or even a majority of biologists is wanting. The examples or cases brought forward by Lamarckians of the alleged inheritance of mutilations, of the results of disease, and of use and disuse, are not convincing. It is one of Weismann's positive contributions to biology to have analyzed case after case of alleged inheritance of acquired characters and shown its falseness, or at least uncertainty. Many of these cases he has been able to explain as a result of selection; others remain inexplicable; a few only are insisted on by the Lamarckian champions as indisputable examples of such inheritance. But this very paucity of so-called proved cases, where there should be thousands of obvious examples if the principle were really sound, is argument against Lamarckism.

"Our knowledge, too, of the mechanism of heredity makes strongly against the theory of the inheritance of acquired characters. Another of Weismann's positive contributions to biology is his generally sound distinction between the germ-plasm and the soma-plasm and parts of the many-celled body. At maturity the animal body is composed of a small mass of germ-plasm (germ-cells), situated in the ovaries or testes, and a great mass of somatic tissues and organs, all the rest of the body, in fact. Now, what is the condition that exists in the body after a somatic part is modified by use or disuse or by other functional stimulus, as when a muscle is enlarged by exercise, the sole of the foot calloused by going barefoot, an ear more finely attuned by training? We have a definite physical change in a definite organ, but is the germ-plasm in any way changed or affected by this superficial or specific somatic modification, or, if changed, is it changed so that it will produce in its future development a similar change in the same organ of the future new individual? What possible mechanism have we in the body to produce or insure such an effect on the germ-plasm? The answer is obvious and flat; we certainly know of no such mechanism; in fact, what we do know of the relation of the germ-cells to the rest of the body makes any satisfactory conception of such a mechanism as yet impossible.

"But even were the inheritance of acquired characters now an established fact, or if it should come to be one, it must be kept in mind that Lamarckism could be substituted only partly for Darwinism. There are many adaptations and much species-forming that Lamarckism might explain, but also there are hosts of adaptations that Lamarckism cannot explain."

A number of American biologists have added to the principles of Lamarck that of natural selection. Without denying to natural selection a more or less important part in the process of organic evolution, members of this school believe that much greater importance ought to be assigned to the inherited effects of use and disuse than was assigned to these agencies by Darwin. It is obvious that neo-Lamarckism has to face the problem of the heredity of acquired characters—this is the fundamental and as yet unproved proposition of the theory.

The Darwinian theory is based upon variations which occur in all directions, unfavorable as well as favorable, and hence are known as indeterminate variations. Definite lines of development are produced from these chance variations by the elimination in the struggle for existence of all other lines; that is, natural selection permits only certain kinds of variation to persist and to accumulate. According to this theory the persistence of the useful is explained, but there are certain phenomena which cannot so easily be explained. Among these may be mentioned development along definite lines which are not advantageous and over-development of parts to a harmful degree. Moreover, there is difficulty in explaining the beginnings of advantageous modifications from fluctuating individual variations. It is to explain these phenomena that the theory of "Orthogenesis" has been developed.

According to the theory of orthogenesis variations are predetermined and hence development is fixed along definite lines. There are various views as to the origin of these predetermined variations. The Lamarckians would base them on the perpetuation and accumulation of the effects of use and disuse, etc.; Roux would explain them on the battle of the parts theory and Weismann on the germinal selection theory, referred to later in this chapter.

Many phases of the theory of orthogenesis have been advanced by Nägeli, Eimer, Cope and others. Some of these go so far as to say that orthogenesis takes the place of natural selection. Nägeli belongs to this school, and he "believes that animals and plants would have developed about as they have even had no struggle for existence taken place and the climate and geologic conditions and changes been quite different from what they actually have been," says Kellogg.

Others hold that orthogenesis is an adjunct of natural selection. Prominent among the latter is Professor Whitman, of Chicago, who sees no fundamental contradictions between the theories and who believes that orthogenesis and natural selection are factors of evolution working together at times; in other words, determinate orthogenetic variations are preserved by natural selection—a conclusion which appeals to many biologists as most reasonable.

Associated with the name of de Vries, the Amsterdam botanist, is the Mutation Theory, or Heterogenesis. But this general conception of species-forming on a basis of the occurrence of occasional, sudden, fixed and often considerable changes or variations in the offspring of a plant or animal is a conception not of course new with de Vries, but one variously expressed by numerous biologists from Darwin's time on, especially by von Kölliker, Galton, Dall, Bateson, Emery, Scott and Korschinsky. It is, however, chiefly due to the patient, persistent, well-planned and extensive experiments and observations of de Vries that this theory of species-forming by heterogenesis, or as called by de Vries, by mutations, has recently received so much renewed attention.

"The meaning of heterogenesis," says Kellogg, "in connection with species-forming and descent is essentially this: Whereas by the Darwinian theory species are transformed slowly and by slight changes in at first one or two or a few and only later in more parts, and all new species are derived from the old ones (which usually disappear as the new ones appear) by the gradual selection of the advantageous ones among the regular slight, fluctuating, individual variations (known commonly as Darwinian variations and which mostly occur according to the law of error), by the theory of heterogenesis new species appear suddenly, not by a selective choosing among the slight, fluctuating Darwinian variations, but independently of selection and largely independently of the so-called Darwinian variations by the appearance in fixed definite form of several to many slight considerable variations, which give the new species definite characteristics differentiating it often in many particulars from the old species, which differentiating characteristics are fully and faithfully transmitted to the succeeding generations of individuals derived from this suddenly born new species."

Extensive observations and experimentation to test the mutation theory are now in progress, and it is too early to form a final opinion as to its bearing on the theory of natural selection. It has been warmly welcomed, but even its friends admit that it needs the support of more experiments and more facts. T. H. Morgan sums up the advantages of the theory as follows: "Since the mutations appear fully formed from the beginning, there is no difficulty in accounting for the incipient stages in the development of an organ, and since the organ may persist, even when it has no value to the race, it may become further developed by later mutations and may come to have finally an important relation to the life of the individual.

"The new mutations may appear in large numbers, and of the different kinds, those will persist that can get a foothold. On account of the large number of times that the same mutations appear, the danger of becoming swamped through crossing with the original form will be lessened in proportion to the number of new individuals that arise.

"If the time of reaching maturity in the new form is different from that in the parent forms, then the new species will be kept from crossing with the parent form, and since this new character will be present from the beginning, the new form will have much better chances of surviving than if a difference in time of reaching maturity had to be gradually acquired.

"The new species that appear may be in some cases already adapted to live in a different environment from that occupied by the parent form, and if so, it will be isolated from the beginning, which will be an advantage in avoiding the bad effects of intercrossing.

"It is well known that the differences between related species consist largely in differences of unimportant organs, and this is in harmony with the mutation theory, but one of the real difficulties of the selection theory.

"Useless or even slightly injurious characters may appear as mutations, and if they do not seriously affect the perpetuation of the race, they may persist."

Still another casual factor of the descent of species is to be found in the isolation theories differently expressed by various authors.

Altho to many biologists isolation alone is sufficient to account for the origin of species, most evolutionists consider it to be a very widespread and effective auxiliary theory to natural selection. Selection needs help from just such a factor. Just what is meant by this theory in its different phases Kellogg describes as follows:

"If, in a species, a number of individuals show a certain congenital variation, this variation will probably be lost by cross-breeding with individuals not having it, unless the individuals having it are in the majority or unless they become in some way isolated from the others and segregated so that they will breed among themselves. By such isolation and such in-and-in breeding the newly appearing congenital variations might soon become established, and if advantageous be so considerably developed as soon to distinguish as a variety or incipient species the members of the isolated colony. With time a distinct new species might result. Are there means to produce such isolation of groups of individuals belonging to a common species?

"The answer to this is certainly an affirmative one. There seem to be, indeed, several means of producing isolation, and the isolation may be variously named accordingly. Undoubtedly the most important of these kinds of isolation, at least in the light of our present knowledge, is that known as geographical or topographical isolation. Isolation produced in other ways may be called biologic or physiologic or sexual isolation. In the case of geographic or topographic isolation the isolated group or groups of individuals are actually in another region or locality from the rest of the species, this being the result of migration, voluntary or involuntary.

"In biologic isolation the individuals of the species all inhabit the same territory, but become separated into groups by structural or physiological characters which prevent miscellaneous inter-breeding. The real founder and most insistent upholder of the theory of species-forming by isolation (geographic and topographic isolation) was Moritz Wagner (1813-1887), a traveler and naturalist, whose wanderings and observations brought to him the conviction that while natural selection might modify species and even produce continuous evolution it could never differentiate species, that is, produce new species."

In support of isolation theories, it is argued by biologists that isolation is very important as one factor in forming species. It is, however, obvious that isolation in itself cannot be the basic and all-sufficient cause for the production of specific differentiation, any more than any selective factor can. The prerequisite in both cases is the occurrence of variation. What are the variations and how are they produced? These are the fundamental questions in species-forming. Isolation is a tremendously favoring condition, but not a primary cause of species-forming. It tends to help along, to hurry up species disintegration, not to initiate it.

The Germinal Selection Theory advanced by Weismann attempts to explain the origin of variations. According to Weismann's neo-Darwinism, only congenital variations, those present at birth, are transmissible by heredity. In brief, the theory holds that the germ-plasm may be influenced by conditions under which an organism lives and may "acquire" variations in a determinate or favorable direction. Knowing this factor, "we remove, it seems to me," writes Weismann, "the patent contradiction of the assumption that the general fitness of organisms or the adaptations necessary to their existence are produced by accidental variations—a contradiction which formed a serious stumbling-block to the theory of selection. Tho still assuming that primary variations are "accidental," I yet hope to have demonstrated that an interior mechanism exists which compels them to go on increasing in a definite direction the moment selection intervenes. Definitely directed variation exists, but not predestined variation running on independently of the life conditions of the organism as

Nägeli, to mention the position that the most extreme advocate of this doctrine has assumed; on the contrary, the variation is such as is elicited and controlled by those conditions themselves, tho indirectly."

There are numerous minor theories proposed to explain difficulties in the more general theories. For these the reader is referred to special books like Kellogg's "Darwinism To-day," Jordan and Kellogg's "Evolution and Animal Life" and Morgan's "Evolution and Adaptation."

Most biologists at present seem inclined to look for truth in a combination of the several theories. Thus Whitman says: "Natural selection, orthogenesis and mutation appear to present fundamental contradictions, but I believe that each stands for truth, and reconciliation is not distant. The so-called mutations of 'Oenothera' are indubitable facts, but two leading questions remain to be answered. First, are these mutations now appearing, as is agreed, independently of variation, nevertheless a production of variations that took place at an earlier period in the history of these plants? Secondly, if species can spring into existence at a single leap, without assistance of cumulative variations, may they not also originate with such assistance? That variation does issue a new species, and that natural selection is a factor, tho not the only factor, in determining results, is, in my opinion, as certain as that grass grows, altho we cannot see it grow. Furthermore, I believe I have found indubitable evidence of species-forming variation advancing in a definite direction (orthogenesis) and likewise of variations in various directions (amphigenesis). If I am not mistaken in this, the reconciliation for natural selection and orthogenesis is at hand."

Others, like H. F. Osborn, think that there are still some unknown factors. Osborn says: "The general conclusion we reach from a survey of the whole field is, that for Buffon's and Lamarck's factors we have no theory of heredity, while the original Darwin factor, or neo-Darwinism, offers an inadequate explanation. If acquired variations are transmitted, there must be, therefore, some unknown principle in heredity; if they are not transmitted, there must be some unknown factor."

CHAPTER XV

HEREDITY

No TOPIC in all biology has received so much attention in recent times, both from investigators and from the intelligent public at large, as Heredity. The reason for this interest is to be found in the importance of heredity for the individual human life, its practical importance in breeding plants and animals and its bearing on the evolutionary theory of biology. Its importance in these lines is clearly related by J. Arthur Thompson, of Aberdeen, in his recent book, "Heredity": "There are no scientific problems of greater human interest than those of Heredity," he declares, "that is to say, the genetic relation between successive generations. Since the issues of the individual life are in great part determined by what the living creature is or has to start with, in virtue of its hereditary relation to parents and ancestors, we cannot disregard the facts of heredity in our interpretation of the past, our conduct in the present or our forecasting of the future. Great importance undoubtedly attaches to Environment in the widest sense—food, climate, housing, scenery and the animate 'milieu'; and to Function in the widest sense,—exercise, education, occupation or the lack of these; but all these potent influences act upon an organism whose fundamental nature is determined, tho not rigidly fixed, by its Heredity, that is, we repeat, by its genetic relation to its forebears. As Herbert Spencer said, 'Inherited constitution must ever be the chief factor in determining character.' And what is important in regard to Man's heredity is even more demonstrably important in regard to his domesticated animals and cultivated plants. What has been achieved in the past in regard to horses and cattle, pigeons and poultry, cereals and chrysanthemums, by experimental cleverness and infinite patience may be surpassed in the future if breeders and cultivators can attain to a better understanding of the more or less obscure laws of inheritance on which all their results depend.

"The study of heredity is also of fundamental importance in the domain of pure science, in the biologist's attempt to interpret the process of evolution by which the complexities of our present-day fauna and flora have gradually arisen from simpler antecedents. For heredity is obviously one of the conditions of evolution, of continuance as well as of progress. There would have been heredity even if there had been a monotonous world of Protists without any evolution at all, but there could not have been any evolution in the animate world without heredity as one of its conditions. The study of heredity is inextricably bound up with the problems of development, reproduction, fertilization, variation and so on; in short, it is one of the central themes of Biology."

Some outline of the reproduction of organisms is a necessary prelude to a discussion of the theories of heredity. It has been stated that as a rule individual plants and animals start as a single cell. In the one-celled organisms the simple division of the parent cell into daughter cells constitutes reproduction. Each of the daughter cells thus formed is a young organism with the power to grow to mature size, divide and complete a life-cycle by reproducing. One unicellular organism to-day may merge its individuality into two offspring in a few hours and then into four in the next few hours and so on.

Many-celled plants and animals begin their individual existence as one-celled ova or ovules which by oft-repeated cell-division produce the thousands of cells found in the body of the larger plants and animals. In these, certain cells are set apart as reproductive cells for the development of new individuals.

As is well known, most higher plants and animals have differentiated into male and female sexes. Each produces a peculiar kind of reproductive or germ cell. In animals the organs of the male known as spermaries produce minute cells (sperm-cells or spermatozoa), provided with a vibratile appendage capable of causing swimming in fluids. The organs of the female known as ovaries produce ova or eggs. These eggs are simple cells, usually incapable of division without fertilization. By swimming a sperm-cell comes into contact with an egg-cell, penetrates and is transformed into a nucleus which moves to meet and fuse with the female nucleus of the egg-cell. This entrance and fusion of sperm-nucleus with egg-nucleus is fertilization. Immediately after the fusion the fertilized egg or oosperm shows signs of preparation for division by mitosis and soon the two-cell stage is formed. In like manner by mitosis cleavage again takes place in each of these two cells and there follow stages of four, eight, sixteen, thirty-two, etc., cells until the egg has been divided into a mass of cells. Cell-division continues, differentiation into tissues takes place and a folding off of organs goes on until the individual is completely formed.

In plants the process is in essentials the same. In the lower plants, even including the mosses and the ferns, the male germ-cells are motile and swim to meet the female germ-cells. They enter and produce changes similar to those described for animals. In the higher flowering plants motile male-cells are not found. Instead there are pollen grains adapted to being carried by winds, insects, etc., from the anther of one flower to the pistil of another. From the pollen grain a delicate tube grows down into the ovary and into contact with the egg-cell or ovule of the plant. Down this tube moves a small cell from the inside of the pollen grain. Its nucleus fuses with the egg-nucleus, producing fertilization and leading soon to cell-division.

In brief outline, the above is the story of the usual origin of higher plants and animals in sexual reproduction. The essential point is that new individuals arise from two cells, one derived from each parent.

Exceptional cases do occur. Some multicellular animals like Hydra and certain worms may give rise to buds or divide into two or more new animals. This is similar to the power of many plants to reproduce from buds, shoots or cuttings. This process is known as asexual reproduction, in which also is classed the simple division of one-celled plants and animals. In most cases organisms with the power of asexual reproduction also multiply by sexual reproduction, but many plants seem to be able to multiply indefinitely by runners, tubers and so on.

Another exception to the general rule that higher individuals develop from the fusion of two germ-cells is found among certain species of plant lice (Aphides), water fleas (small crustacea) and others which under certain conditions develop from unfertilized eggs. This is parthenogenesis. With the possible exception of certain scale insects, parthenogenesis among animals is always temporary and parthenogenetic generations are from time to time, usually in the fall, succeeded by a generation reproducing sexually. Among plants many species are believed to be permanently parthenogenetic.

When such cases are considered, it must be admitted that the vital processes may continue indefinitely simply by repeated division of the cells themselves, without the intervention of the act of fertilization; still, on the other hand, it is necessary to conclude, on account of the wide distribution throughout the whole organic kingdom of the phenomenon of fertilization, that this institution is of essential importance among the vital processes and that it is fundamentally connected with the life of the cell.

For an understanding of the problems of heredity the method of development, of sperms, "spermatogenesis," and of ova, "oogenesis," is necessary as well as the exact steps of the process by which an oosperm or unicellular embryo is formed by the union of the two sexual elements. In plants and animals both ovary and spermary are at first composed of cells of the ordinary kind, the primitive sex-cells, and it is only by the further development of these that the sex of the gonad is determined.

In the spermary the sex-cells undergo repeated fission, forming what are known as the sperm-mother-cells, in which the number of chromosomes is constant in any given species. The sperm-mother-cell divides and the result of division is immediately repeated, the result being that each sperm-mother-cell gives rise to a group of four cells having half the normal number of chromosomes, the four cells so produced being the immature sperms. Thus the sperm or male gamete is a true cell, and is specially modified in most cases for active movements. This mitotic division by which the number of chromosomes in the sperm-mother-cells is reduced by one-half is known as a reducing division.

As already stated, the ova also arise from primitive sex-cells. These divide and give rise to the egg-mother-cells. The egg-mother-cells do not immediately undergo division, but remain passive and increase, often enormously, in size, by the absorption of nutriment from surrounding parts; in this way each egg-mother-cell becomes an ovum. In addition to increase in the bulk of the protoplasm itself, a formation of plastic products usually goes on to an immense extent and the ovum may attain a comparatively enormous size, as, for instance, in birds, in which the "yolk" is simply an immense egg-cell.

Such an ovum is incapable of being fertilized or of developing into an embryo; before it is ripe for conjugation with a sperm or able to undergo the first stages of segmentation it has to go through a process known as the maturation of the egg. Maturation consists essentially in a twice-repeated process of cell-division by mitosis, and by its means two small cells called polar cells are thrown off. The ovum has now lost a portion of its protoplasm, together with three-fourths of its chromatin, half having passed into the first polar cell and half of what remained into the second: the remaining one-fourth of the chromatin takes on a rounded form and is distinguished as the female pronucleus. The formation of both polar cells takes place by a reducing division, so that while the immature ovum contains the number of chromosomes found in the ordinary cells of the species, the mature ovum, like the sperm, contains only one-half the normal number.

Shortly after, or in some cases before maturation, the ovum is fertilized by the conjugation with it of a single sperm. Sperms are produced in vastly greater numbers than ova, and it often happens that a single egg is seen quite surrounded with sperms, all apparently about to conjugate with it. It has, however, been found to be a general rule that only one of these actually conjugates; the others, like the drones in a beehive, perish without fulfilling the one function they are fitted to perform.

The sperm and egg nuclei approach one another and finally unite to form what is called the segmentation nucleus, the single nucleus of what is not now the ovum, but the oosperm—the impregnated egg or unicellular embryo. The fertilizing process is thus seen to consist of the union of two nuclear bodies, one contributed by the male gamete or sperm, the other by the female gamete or ovum. It follows from this that the essential nuclear matter or chromatin of the oosperm is derived in equal proportions from each of the two parents. Moreover, as both male and female pronuclei contain only half the number of chromosomes found in the ordinary cells of the species, the union of the pronuclei results in the restoration of the normal number to the oosperm.

Fertilization being thus effected, the process of segmentation, or division of the oosperm, takes place as described. The significance of these observed phenomena of maturation, fertilization and cell-division in modern theories of inheritance will be apparent.

The main facts of organic reproduction which are fundamental to a consideration of the modern problems of heredity having been outlined, a brief survey of some of the most prominent theories of heredity which have been advanced during the last two centuries will be given, after which attention will be directed to the present-day problems of heredity, including "Mendelism," or the experimental study of heredity, and those cytological problems which have as their aim the identification of the inheritance material in the germ-cells.

It is not strange that of the many attempts at theories of heredity the early ones were essentially mystical and fell back on the supernatural to explain what could not be seen. Throughout the seventeenth and eighteenth centuries there prevailed a theory of preformation. The believers in this theory, men like Bonnet and Haller, maintained the preformations of the organism and all its parts within the egg. They regarded the apparent new formation of organs during development as an illusion, and held that development was merely an unfolding of this preformed miniature. Moreover, they believed that the germ contained not only a preformation of the organism into which it was to grow, but of successive generations as well. To quote from Thomson: "Preformed miniature lay within preformed miniature in ever-increasing minuteness, as if in a conjurer's box. Thus it was computed that Mother Eve must have included over 200,000 millions of homunculi, or sometimes it was Adam who was made to bear this burden. For according to one party, the ovists—*e.g.*, Malpighi—it was the ovum that contained the miniature which had to be unfolded; while according to others—the animalculists—it was the sperm which contained the preformed model." But how the germ came to have this preformed model they could not tell.

Caspar Friedrich Wolff was the first to raise a strong protest against the speculations of the preformationists and to advance a new theory. Appealing to facts, he showed that in the early stages of the chick's development there was no visible hint of a preformed miniature. but that various organs made their appearance successively and gradually and were to be seen being formed. He held that there is a new formation, or "epigenesis." But how the germ that seems to start anew every time can develop as it does the upholders of the theory of epigenesis could not tell. For their ultimate explanations of heredity both schools fell back on the assumption of hyperphysical agencies as the earlier theorists had done before them.

Passing from these mystical interpretations of the phenomena of heredity, there are a whole series of theories which are in varying degrees scientific and may be fairly described by the general designation pangenetic. Thomson in "The Science of Life" and in "Heredity" gives good accounts of the various theories of heredity. From these works the material in this section has been taken. These theories all have this in common, that they seek to explain the uniqueness of the germ-cell by regarding it as a center of contributions from different parts of the organism—a collection of samples from the various organs. Spencer, Darwin, Jäger, Galton, Brooks and others at one time or another contributed toward these theories.

In 1864 Spencer suggested the existence of "physiological units" derived from and capable of development into cells, and supposed that they accumulated in the germ-cells, which thus became in a conceivable sense miniature organisms. The best-known theory of this class is the "provisional hypothesis of pangenesis" enunciated by Darwin in 1868. The main suggestions of this theory are as follows:

Every cell of the body, not too highly differentiated, throws off characteristic gemmules;

These multiply by fission, retaining their characteristics;

They become specially concentrated in the reproductive elements in both sexes;

In development the gemmules unite with others like themselves, and grow into cells like those from which they were originally given off, or they remain latent during development through several generations.

By means of this theory Darwin attempted to explain not only the simpler facts of heredity, but also "those very curious but abundant cases in which a character is transmitted in a latent form and at last reappears after many generations, such cases being known as 'atavism,' or 'reversion'; and again, those cases of latent transmission in which characteristics special to the male are transmitted to the male offspring through the female parent without being manifest in her; and yet again, the appearance at a particular period of life of characters inherited and remaining latent in the young organism," as Lankester expresses it.

The great defect of this theory is obviously its entirely hypothetical character—no one has ever observed any gemmules. Moreover, it is not in harmony with the results of experiments—*e.g.*, on transfusion of blood—or with what is known of the physiology of cells or with the facts of experimental inheritance.

The next theory to be noted is the theory of Genetic or Germinal Continuity. This theory was first suggested by Owen in 1849. Since then Häckel, Jäger, Brooks, Galton, Nussbaum, Weismann, and a score of others have contributed toward it.

In its earlier conception this germinal continuity consisted in a continuity of germ-cells. A summary of this idea follows.

At an early stage in the embryo, the future reproductive cells of the organism are often distinguishable from those which are forming the body.

The latter develop in manifold variety and lose almost all likeness to the mother germ.

The former—the reproductive rudiments—are not implicated in the differentiation of the "body," remain virtually unchanged, and continue the protoplasmic tradition unaltered.

As the sex-cells of the offspring are thus continuous with the parental sex-cells which give rise to it, they will in turn develop into similar organisms.

In this view the reproductive cells form a continuous chain and the reproduction of like by like is natural and necessary. But a serious difficulty besets this doctrine, for a direct chain of cellular continuity can only be said to exist in a few cases. Thus this theory of the continuity of the germ-cells has been replaced by the newer theory of the continuity of the germ-plasm.

This is Weismann's theory. Weismann has worked it out in the minutest details. The problems which he discusses are too intricate and technical for any but a special student. For present purposes a very brief summary as expressed by Thomson will be sufficient.

"A living creature usually takes its origin from a fertilized egg-cell, from a union of an ovum and a spermatozoon. These germ-cells are descended by a continuous cell-division from the fertilized ova which gave rise to the two parents; they have retained the organization of the fertilized ova, and this organization has its vehicle in the chromatin of the nucleus—the germ-plasm. This germ-plasm consists of several chromosomes or idants, each of which is made up of several pieces or ids, each of which (here hypothesis begins) is supposed to contain all the potentialities—generic, specific, and individual—of a new organism. Each id is a microcosm with an architecture which has been elaborated for ages; it is supposed to consist of numerous determinants, one for each part of the organism that is capable of varying independently or of being independently expressed during development. Lastly, each determinant is pictured as consisting of a number of ultimate vital particles of biophores, which are eventually liberated in the cytoplasm of the various embryonic cells. All these units of various grades are capable of growth and of multiplication by division."

In its more general aspects this view of Weismann's represents what might be called the dominant modern view. That is, there is general belief that the germ-cell inherits from the parental germ-cells an organization of great complexity, including an intricate architecture of minute particles which are the material bearers of particular inheritance qualities. Not all biologists, however, agree with Weismann in his limitation of the inheritance material to the chromosomes. It is here that the inheritance problems of to-day have their beginning.

Much attention has in recent years been given to the experimental study of variation and heredity. These experiments are of interest in connection with Mendel's law, a law so important in the science of biology that Professor Bateson has written of it, "The Experiments which led to this advance in knowledge are worthy to rank with those that laid the foundation of the atomic laws of chemistry." The discoverer of this law was Gregor Johann Mendel (1822-1884), an Augustinian monk. He was a man of varied interests, and in his gardens performed many hybridization experiments on plants. In 1866 he published a paper giving the result of his experiments, entitled "Experiments in Plant Hybridization." This paper did not attract much attention at the time, probably because of the enthusiasm and the controversy evoked by the natural selection theory, and lay practically unknown in the Proceedings of the Natural History Society of Brünn for over thirty years. A revival of interest in the experimental study of variation and heredity at about the beginning of the present century led to the rediscovery of the Mendelian principles of heredity by several botanists working separately, and about that time Bateson brought into prominence Mendel's work and by a long series of experiments confirmed and extended it.

To gain an idea of the scope of these principles one cannot do better than turn to Mendel's own account of his experiments. Punnett's "Mendelism" and Thomson's "Heredity" give such an account, and from these sources the following statements have largely been taken.

In the selection of a plant for experiment Mendel recognized that two conditions must be fulfilled. In the first place, the plant must possess differentiating characters, and secondly, the hybrids must be protected from the influence of foreign pollen during the flowering period. In the edible pea Mendel found an almost ideal plant to work with. The separate flowers are self-fertilizing, while complications from insect-interference are practically non-existent. As is well known, there are numerous varieties of the eating-pea exhibiting characters to which they breed true. In some varieties the seed color is yellow, while in others it is green. In some varieties the seeds are round and smooth when ripe; in others they are wrinkled. Some peas have purple, others have pure white flowers. Some peas again, when grown under ordinary conditions, attain to a height of 6 to 7 feet, while others are dwarfs which do not exceed 1½ to 2 feet.

Mendel selected a certain number of such differentiating characters and investigated their inheritance separately for each character. Thus in one series of experiments he concentrated his attention on the heights of the plants. Crosses were made between tall and dwarf varieties, which previous experience had shown to come true to type with regard to these characters. It mattered not which was the pollen-producing and which the seed-bearing plant. In every case the result was the same. Tall plants resulted from the cross. For this reason Mendel applied the terms "Dominant" (D) and "Recessive" (R) to the tall and dwarf habits respectively.

In the next generation the cross-bred plants (products of D and R or R and D, but all apparently like D) were allowed to fertilize themselves, with the result that their offspring exhibited the two original forms, on the average three dominants to one recessive. Out of 1,064 plants, 787 were tall, 277 were dwarfs.

When these recessive dwarfs were allowed to fertilize themselves they gave rise to recessive dwarfs only for any number of generations. The recessive character bred true.

When the dominants, on the other hand, were allowed to fertilize themselves, they produced one-third of "pure" dominants (producing dominants only when self-fertilized) and two-thirds of cross-bred dominants, which on self-fertilization again gave rise to a mixture of dominants and recessives in the proportion of 3: 1.

If in an experiment with mice a gray house-mouse is crossed with a white mouse, the offspring are all gray. Grayness is dominant; albinism is recessive. The gray hybrids are inbred; their offspring are gray and white in the proportion 3: 1. If these whites are inbred they show themselves "pure," for they produce whites only for subsequent generations. But when the grays are inbred they show themselves of two kinds, for one-third of them produce only grays, which go on producing grays; while the other two-thirds, apparently the same, produce both grays and whites. And so it goes on.

In his exceedingly clear exposition of Mendelism (1905) R. C Punnett states the result thus: "Wherever there occurs a pair of differentiating characters, of which one is dominant to the other, three possibilities exist: there are recessives which always breed true to the recessive character; there are dominants which breed true to the dominant character, and are therefore pure; and thirdly, there are dominants which may be called impure, and which on self-fertilization (or inbreeding, where the sexes are separate) give both dominant and recessive forms in the fixed proportion of three of the former to one of the latter."

To explain such phenomena Mendel suggested that the hybrid produces in equal numbers two kinds of germ-cells (two kinds of egg-cells or two kinds of pollen-grains)—that there is in the developing reproductive organ a segregation of germ-cells into two equal camps, one camp with the potential quality of tallness, the other camp with the potential quality dwarfness. Thus, if there are six ovules, three contain in their egg-cell the primary constituent corresponding to tallness, and three contain the primary constituent corresponding to dwarfness. Each of these is pollinated by a pollen-grain, which, by hypothesis, contains the potential quality of tallness or of dwarfness; and if the two kinds of pollen-grains are present in equal numbers, each ovule has an equal chance of being fertilized by a pollen-grain with a potential quality of tallness or by a pollen-grain with a potential quality of dwarfness. Therefore the result must be set of offspring partly dominant and partly recessive in the proportions of 3: 1.

Mendel discovered an important set of facts, and he also suggested a theoretical interpretation—the theory of gametic segregation. As Bateson says, "The essential part of the discovery is the evidence that the germ-cells or gametes produced by cross-bred organisms may in respect of given characters be of the pure parental types, and consequently incapable of transmitting the opposite character; that when such pure similar gametes of opposite sexes are united in fertilization, the individuals so formed and their posterity are free from all taint of the cross; that there may be, in short, perfect or almost perfect discontinuity between these germs in respect of one of each pair of opposite characters."

This law of the segregation of gametes accords well with the experimental and observed phenomena of heredity. But this brings up the question, Is there any known process by which such a segregation could be brought about during the history of the germ-cells? "Is it," says Thomson, "enough simply to say that the germ-cells are little living unities with an organization, an equilibrium of their own, and that they tend as they multiply to become more stable—namely, by separating out incompatibilities (dominant and recessive potential unit characters) and becoming the vehicle of either the one or the other? Are there differential divisions during the development of the germ-cells which lead to there being two camps of gametes which we may briefly describe as pure potential dominants and pure potential recessives? Is this not a possible expression of a struggle between the hereditary items and in line with Weismann's theory of germinal selection?"

"A more precise suggestion," says T. H. Morgan, "to which it seems too soon to attach great significance, is the fascinating hypothesis that the segregation occurs during the maturation division. If we assume that the chromosomes are the vehicles of the hereditary qualities, which seems highly probable; if we assume, further, that a particular potential unit character is contained in each germ-cell in one chromosome and not in others, which seems a difficult assumption; then it is possible that Sutton may be correct in his suggestion that the segregation of gametes into two sets occurs in the course of the maturation division."

A great deal of work confirming Mendel's experiences has been done both with plants and animals in laboratories in many countries, with the result that altho there are some difficulties and not a few discrepancies, "the truth of the law," as Bateson says, "is now established for a large number of cases of most dissimilar character."

On the other hand, there has been much experimentation in which the results do not harmonize with the Mendelian results. Thomson says: "There seems at present no reason to believe that the Mendelian formula has more than a limited application, tho it is of course possible that apparent exceptions may eventually turn out to be less formidable than they seem. There seems no reason why there should not be several formulæ of inheritance, each applicable to particular sets of cases—*e.g.*, to cases where blending does occur and to cases where it never occurs. As the method of experiment is obviously the surest line of progress, the more it is prosecuted the sooner will the mists surrounding heredity disappear, but progress cannot be secured by ignoring difficult cases or by straining the formula in the eager desire to universalize it."

Extensive theoretical and practical applications of Mendel's law to problems of biology have been made. For the technical discussion of Mendel's law in connection with persistence in evolution and in relation to definite variations, reference must be made to some of the detailed studies on Mendelism. The following illustrations from Thomson and from Punnett will show its value to practical breeders.

Some kinds of wheat are very susceptible to the fungoid disease known as "rust"; others are immune. The quality of immunity to rust is recessive to the quality of predisposition to rust. When an immune and a non-immune strain are crossed together the resulting hybrids are all susceptible to "rust." On self-fertilization such hybrids produce seed from which appear dominant "rusts" and recessive immune plants in the expected ratio of 3: 1. From this simple experiment the phrase "resistance to disease" has acquired a more precise significance, and the wide field of research here opened up in this connection promises results of the utmost practical as well as theoretical importance.

"The new science of heredity has much to teach the practical man," says Punnett. "Let us suppose that he has two varieties, each possessing a desirable character, and that he wishes to combine these characters in a third form. He must not be disappointed if he makes his cross and finds that none of the hybrids approach the ideal which he has set before himself; for if he raises a further generation he will obtain the thing which he desires. He may, for example, possess tall green-seeded and dwarf yellow-seeded peas, and may wish to raise a strain of green dwarfs. He makes his cross—and nothing but tall yellows result. At first sight he would appear to be further than ever from his end, for the hybrids differ more from the plant at which he is aiming than did either of the original parents.

"Nevertheless, if he sow the seeds of these hybrids he may look forward with confidence to the appearance of the dwarf green. And owing to the recessive nature of both greenness and dwarfness, he can be certain that for further generations the dwarf greens thus produced will come true to type. The green dwarfs are all fixed as soon as they appear, and will throw neither talls nor yellows. The less the hybrids resemble the form at which the breeder aims, the more likely is that form to breed true when it appears in the next generation."

In the years since 1900 there has been deep interest in the microscopic study of germ-cells in the search for the mechanism of heredity. Much observation and experimentation has been done and there has been a rapid advance in knowledge, but so intricate are the questions involved that investigation is most difficult and only a start at the problems has been made. In an address before the American Association for the Advancement of Science in December, 1907, E. G. Conklin well summarizes the arguments in support of the two general views under which opinions concerning the material bearers of inheritance may be said to be grouped, namely, the view that the chromosomes of the germ-cell are the bearers of heredity and the view that inheritance may take place through the cytoplasm of the germ-cells. A few of the less technical paragraphs of this paper are as follows:

"In practically all theories of heredity it is assumed that there is a specific 'inheritance material,' distinct from the general protoplasm, whose function is the 'transmission' of hereditary properties from generation to generation, and whose characteristics, as compared with the general protoplasm, are greater stability, independence and continuity. This is the Idioplasm of Nägeli, the Germ-plasm of Weismann. It is further assumed that this germ-plasm is itself composed of ultramicroscopical units, which are capable of undergoing transformation during the course of development into the structures of the adult. However necessary such units may be for a complete philosophical explanation of development, it must be confessed that at present they constitute a purely hypothetical system which may or may not correspond to reality. We know that the germ-cells are exceedingly complex, that they contain many visible units such as chromosomes, chromomeres and microsomes, and that with every great improvement in the miscroscope and in microscopical technique other structures are made visible which were invisible before, and whether the hypothetical units just named are present or not seems to be a matter of no great importance, seeing that, so far as the analysis of the microscope is able to go, there are differentiated units which are combined into a system—in short, there is organization.

"On the other hand, the evidence in favor of an inheritance material, which is distinct from the general protoplasm of the germ and whose function is the reproduction of hereditary characters, is not convincing. All the living substance of the egg cell is converted into the mature organism. That there is a species plasm or an individual plasm which is continuous from generation to generation, and from which all the qualities of the mature organism are differentiated, is almost a certainty, but there is no satisfactory evidence that this substance is distinct from the general protoplasm of the young germ-cells.

"Differentiation, and hence heredity, consists in the main in the appearance of unlike substances in protoplasm and their localization in definite regions or cells.

"Unfortunately, we do not know many of the steps by which differing substances appear within protoplasm. But in all cases which have been carefully studied one significant fact appears, viz., the importance of the interaction of the nucleus and cytoplasm. In many cases various substances have been seen to come out of the nucleus and to mingle with the cytoplasm, while the nucleus in turn absorbs substances from the cytoplasm. It is known that constructive metabolism, differentiation and regeneration never occur in the absence of a nucleus.

"Turning now to the differentiations of the fertilized egg cell, we find that different substances appear in the egg cell and become localized in different regions of the egg or embryo. It is known that there is an active interchange of nuclear and cytoplasmic substances. In the long growth period of the egg the nucleus grows enormously, evidently at the expense of substances received from the cell body. On the other hand, it is well established that substances issue from the nucleus into the cell body and mingle with the cytoplasm during this stage.

"Finally, we may conclude that the nucleus plays a less important rôle in the localization of different substances than in the formation of those substances. Nevertheless, in differentiation, as well as in metabolism, there is every reason to believe that the entire cell is a physiological unit. Neither the nucleus nor the cytoplasm can exist long independently of the other; differentiations are dependent upon the interaction of these two parts of the cell; the entire germ-cell, and not merely the nucleus or cytoplasm, is transformed into the embryo or larva; and it therefore seems necessary to conclude that both nucleus and cytoplasm are involved in the mechanism of heredity.

"It may be considered as definitely settled that the early development of animals is of purely maternal type, and that it is only after the broad outlines of development and the general type of differentiation have been established that the influence of the spermatozoon begins to make itself felt; and it is equally certain that this type of differentiation is predetermined in the cytoplasm of the mature egg cell rather than in the egg nucleus.

"On the other hand, there is no doubt that the differentiations of the egg cytoplasm have arisen, in the main, during the ovarian history of the egg, and as a result of the interaction of nucleus and cytoplasm; but the fact remains that at the time of fertilization the hereditary potencies of the two germ-cells are not equal, all the early development, including the polarity, symmetry, type of cleavage, and the relative positions and proportions of future organs, being predetermined in the cytoplasm of the egg-cell, while only the differentiations of later development are influenced by the sperm. In short, the egg cytoplasm fixes the type of development and the sperm and egg nuclei supply only the details.

"This conclusion is not a refutation of the nuclear inheritance theory, but it is a profound modification of it. At once it destroys the argument that since there is equality of inheritance from both parents there must be equivalence of inheritance material in egg and sperm. So far as those characteristics are concerned which appear late in development, it is highly probable that there is equality of inheritance from both parents, but in the early and main features of development, hereditary traits, as well as material substance, are derived chiefly from the mother.

"In the light of the conclusion that only the later and more detailed differentiations are influenced by the sperm, it follows that experimental work which aims to modify the fundamental features of an organism must be directed to the ovarian egg rather than to the sperm or to the developing embryo."

In conclusion, the following paragraphs from E. B. Wilson's "The Cell in Development and Inheritance" will indicate the present state of the cytological study of inheritance problems and the outlook for the future. "We have now arrived," he says, "at the farthest outposts of cell-research, and here we find ourselves confronted with the same unsolved problems before which the investigators of evolution have made a halt. For we must now inquire what is the guiding principle of embryological development that correlates its complex phenomena and directs them to a definite end. However we conceive the special mechanism of development, we cannot escape the conclusion that the power behind it is involved in the structure of the germ-plasm inherited from foregoing generations.

"What is the nature of this structure and how has it been acquired? To the first of these questions we have as yet no certain answer. The second question is merely the general problem of evolution stated from the standpoint of the cell-theory. The first question raises once more the old puzzle of preformation or epigenesis. The pangen-hypothesis of de Vries and Weismann recognizes the fact that development is epigenetic in its external features; but, like Darwin's hypothesis of pangenesis, it is at bottom a theory of preformation, and Weissman expresses the conviction that it is an impossibility.

"The truth is that an explanation of development is at present beyond our reach. The controversy between preformation and epigenesis has now arrived at a stage where it has little meaning apart from the general problems of physical causality. What we know is that a specific kind of living substance, derived from the parent, tends to run through a specific cycle of changes during which it transforms itself into a body like that of which it forms a part; and we are able to study with greater or less precision the mechanism by which that transformation is effected and the conditions under which it takes place. But despite all our theories, we no more know how the organization of the germ-cell involves the properties of the adult body than we know how the properties of hydrogen and oxygen involve those of water. So long as the chemist and physicist are unable to solve so simple a problem of physical causality as this, the embryologist may well be content to reserve his judgment on a problem a hundredfold more complex.

"The second question, regarding the historical origin of the idioplasm, brings us to the side of the evolutionists. The idioplasm of every species has been derived, as we must believe, by the modification of a preëxisting idioplasm through variation and the survival of the fittest. Whether these variations first arise in the idioplasm of the germ-cells, as Weismann maintains, or whether they may arise in the body-cells and then be reflected back upon the idioplasm, is a question to which the study of the cell has thus far given no certain answer. Whatever position we take on this question, the same difficulty is encountered, namely, the origin of that coördinated fitness, that power of active adjustment between internal and external relations, which, as so many eminent biological thinkers have insisted, overshadows every manifestation of life. The nature and origin of this power is the fundamental problem of biology.

"It may be true, as Schwann himself urged, that the adaptive power of living beings differs in degree only, not in kind, from that of unorganized bodies. It is true that we may trace in organic nature long and finely graduated series leading upward from the lower to the higher forms, and we must believe that the wonderful adaptive manifestations of the more complex forms have been derived from simpler conditions through the progressive operation of natural causes. But when all these admissions are made, and when the conserving action of natural selection is in the fullest degree recognized, we cannot close our eyes to two facts: first, that we are utterly ignorant of the manner in which the idioplasm of the germ-cell can so respond to the influence of the environment as to call forth an adaptive variation; and second, that the study of the cell has on the whole seemed to widen rather than to narrow the enormous gap that separates even the lowest forms of life from the inorganic world.

"I am well aware that to many such a conclusion may appear reactionary or even to involve a renunciation of what has been regarded as the ultimate aim of biology. In reply to such a criticism, I can only express my conviction that the magnitude of the problem of development, whether ontogenetic or phylogenetic, has been underestimated; and that the progress of science is retarded rather than advanced by a premature attack upon its ultimate problems. Yet the splendid achievements of cell-research in the past twenty years stand as the promise of its possibilities for the future, and we need set no limit to its advance. To Schleiden and Schwann the present standpoint of the cell-theory might well have seemed unattainable. We cannot foretell its future triumphs, nor can we doubt that the way has already been opened to better understanding of inheritance and development."

CHAPTER XVI

ADAPTATION

Altho but one element of organic development, the origin of species, has been emphasized in the preceding pages, it has been noticed perhaps in the various discussions brought up that the advance in organic complexity is concerned not only with the great variety of life kinds, but also with the "adaptedness of adaptiveness of life kinds" to various sorts of life-conditions. As Kellogg phrases it, "The task of a life-process explanation is a double one; it must explain not only diversity or variety in life, but adaptive diversity or variety."

The most striking fact in nature is this adaptation of organisms to their environment. On every side plants and animals seem to be well fitted to their particular places in nature. Every organism seems to have been constructed after an ideal plan, and it is not surprising that many early observers of nature believed that each plant and animal was specially designed and created to fit the places in nature which they fill. Verworn says:

"The fact of purposefulness in living nature, which was so marvelous to men of science in early times even down to the middle of the present century, forced them constantly to embrace teleology—*i.e.*, the hypothesis of a fore-ordained plan of creation. [A new teleology of truer understanding finds many exponents among advanced thinkers.] This purposefulness in nature is the simple expression—or, better, the result—of the adaptation of organisms to the vital conditions in the widest sense."

Thus all animals have their essential organs adapted to habitat, food and various conditions of environment. Fishes have limbs in the form of fins, which function very perfectly as rowing-organs; terrestrial vertebrates have in place of fins legs for walking and creeping upon dry land; birds have wings constructed most fittingly with which their light bodies, supported by bones containing air, soar through the air so perfectly that imitation of them is difficult.

Likewise plants are so perfectly adapted to their surroundings in the general plan and arrangement of root, stem, leaf, flower, etc., that only the special student is likely to recognize the adaptation. In fact, these general adaptations of organs and functions of plants and animals are so universal that they have ceased to excite wonder and are taken as necessary phenomena of life. They are necessary phenomena of life, for general adaptations are as natural as breathing, eating and so on.

In addition to the general adaptations to widespread conditions of environment—*e.g.*, to the general conditions under which all land animals and plants or all aquatic animals and plants must live—there are myriads of special adaptations. For example, all fishes living in fresh water have in common general adaptations to an aquatic life, but fishes living in caverns have in addition to the general adaptations certain special adaptive modifications in accordance with their special environment, especially in the eyes, which are profoundly modified in accordance with a life spent habitually in darkness. Likewise all plants living on land have a general adaptation to terrestrial life, but in addition many have special adaptations. All plants which have green leaves use them for starch formation under the action of sunlight, but special adaptations fit certain species to different degrees of light intensity, and as a result one plant may be fitted to grow in open fields while another will grow but in shaded places.

Special adaptations have attracted much attention from students because by contrast with general adaptations they prove valuable in evolutionary studies. For the sake of convenience the special adaptations of plants and animals will be considered separately, and also color adaptations will be treated in a separate section. However, this is purely an arbitrary division, for all studies of the special adaptations of plants and animals lead to the same conclusion—namely, that these adaptations have originated through the processes of evolution.

One of the best collections of facts concerning special adaptations is to be found in the extended chapter on this subject in Jordan and Kellog's "Evolution and Animal Life," from which some of the most striking examples have been selected for use here.

The various types of special adaptations may be roughly divided into five classes as follows: Food-securing, self-defense, defense of young, rivalry and adjustment to surroundings.

"For the purpose of capture of their prey, most carnivorous animals are provided with strong claws, sharp teeth, hooked beaks and other structures familiar to us in the lion, tiger, dog, cat, owl and eagle. Insect-eating mammals have contrivances especially adapted for the catching of insects. The ant-eater, for example, has a long sticky tongue which it thrusts forth from its cylindrical snout deep into the recesses of the ant-hill, bringing it out with its surface covered with ants. Animals which feed on nuts are fitted with strong teeth or beaks for cracking them. Strong teeth are found in those fishes which feed on crabs or sea urchins. Those mammals like the horse and cow, that feed on plants, have usually broad chisel-like incisor teeth for cutting off the foliage, and teeth of very similar form are developed in different groups of plant-eating fishes. Molar teeth are found when it is necessary that the food should be crushed or chewed, and the sharp canine teeth go with a flesh diet. The long neck of the giraffe enables it to browse on the foliage of trees in grassless regions.

"Insects like the leaf-beetles and the grasshoppers, that feed on the foliage of plants, have a pair of jaws, broad but sharply edged, for cutting off bits of leaves and stems. Those which take only liquid food, as the butterflies and sucking bugs, have their mouth parts modified to form a slender, hollow sucking beak or proboscis, which can be thrust into a flower nectary or into the green tissues of plants or the flesh of animals to suck up nectar or plant sap or blood, according to the special food habits of the insect. The honey-bee has a very complicated equipment of mouth parts fitted for taking either solid food like pollen or liquid food like the nectar of flowers. The mosquito has a 'bill' composed of six sharp, slender needles for piercing and lacerating the flesh and a long tubular under lip through which the blood can flow into the mouth. Some predacious insects, as the praying horse, have their fore legs developed into formidable grasping organs for seizing and holding their prey.

"For self-protection the higher animals depend largely on the same organs and instincts as for the securing of food. Carnivorous beasts use tooth and claw in their own defense, as well as in securing their prey, but these, as well as other animals, may protect themselves in other fashions. Many of the higher animals are provided with horns, structures useless in procuring food but effective as weapons of defense. Others defend themselves by blows with their strong hoofs. Among the reptiles and fishes and even among the mammals the defensive coat of mail is found in great variety. The crab and lobster, with claws and carapace, are well defended against their enemies, and the hermit crab, with its well-known habitude of thrusting its unprotected body within a cast-off shell of a sea snail, finds in this instinct a perfect defense. Insects also, especially beetles, are protected by their coats of mail. Scales and spines of many sorts serve to defend the bodies of reptiles and fishes, while feathers protect the bodies of birds and hair those of most mammals."

The ways in which animals make themselves disagreeable or dangerous to their captors are almost as varied as the animals themselves. Besides the teeth, claws and horns of ordinary attack and defense, there are found among the mammals many special structures or contrivances which serve for defense through making their possessors unpleasant.

The turtles are all protected by bony shields, and some of them, the box turtles, may close their shields almost hermetically. The snakes broaden their heads, swell their necks or show their forked tongues to frighten their enemies. Some of them are further armed with fangs connected with a venom gland, so that to most animals their bite is deadly.

Even the fishes have many modes of self-defense through giving pain or injury to animals who would swallow them. The catfish, or horned pout, when attacked sets immovably the sharp spine of the pectoral fin, inflicting a jagged wound. Pelicans which have swallowed a catfish have been known to die of the wounds inflicted by the fish's spine. In the group of scorpion fishes and toad fishes are certain genera in which these spines are provided with poison glands. Many fishes are defended by a coat of mail or a coat of sharp spines. The globe fishes and porcupine fishes are for the most part defended by spines, but their instinct to swallow air gives them an additional safeguard. When one of these fishes is disturbed it rises to the surface, gulps air until its capacious stomach is filled and then floats, belly upwards, on the water. It is thus protected from other fishes, tho easily taken by man.

The torpedo, electric eel, electric catfish and star-gazer surprise and stagger their captors by means of electric shocks. The shock is felt severely if the fish be stabbed with a knife or metallic spear. The electric eel of the rivers of Paraguay and southern Brazil is said to give severe shocks to herds of wild horses driven through the streams, and similar accounts are given of the electric catfish of the Nile. In tropical seas the tangs, or surgeon fishes, are provided with a knife-like spine on the side of the tail, the sharp edge directed forward and slipping into a sheath. This is a formidable weapon when the fish is alive.

Other fishes defend themselves by spears (swordfish, spearfish, sailfish), or by saws (sawfish, sawshark), or by paddles (paddlefish). Others still make use of sucking disks of one sort or another (as in the snailfish, the clingfish and the goby) to cling to the under side of rocks, or as in the Remora, to the bodies of swift-moving sharks. Blind fishes in the caves are adapted to their condition. In similar circumstances salamanders, crayfishes and insects are also blind. Some fishes, as the lancelet, lie buried in the sand all their lives. Others, as the sand darter and the hinalea, bury themselves in the sand at intervals to escape from their enemies. Some fishes called the flying fishes sail through the air with a grasshopper-like motion that closely imitates true flight.

Among the insects the possession of stings is not uncommon. The wasps and bees are familiar examples of stinging insects, but many other kinds less familiar are similarly protected. All insects have their bodies covered with a coat of armor, composed of a horny substance called chitin. In some cases this chitinous coat is very thick and serves to protect them effectually. This is especially true of the beetles.

Some insects are inedible and are conspicuously colored so as to be readily recognized by insectivorous birds.

The protection of the young is the source of many adaptive structures as well as of the instincts by which such structures are utilized. In general those animals are highest in development, with the best means of holding their own in the struggle for life, that take best care of their young. Those instincts which lead to home building are all adaptations for preserving the young. Among the lower or more coarsely organized birds, such as the chicken, the duck and the auk, as with the reptiles, the young animal is hatched with well-developed muscular system and sense organs and is capable of running about and, to some extent, of feeding itself. Birds of this type are known as præcocial, while the name altricial is applied to the more highly organized forms, such as the thrushes, doves and song birds generally. With these the young are hatched in a wholly helpless condition, with ineffective muscles, deficient senses and dependent wholly upon the parent. The altricial condition demands the building of a nest, the establishment of a home and the continued care of one or both of the parents. In the Marsupials—the kangaroo, opossum, etc.—the young are born in a very immature state and are at once seized by the mother and thrust into a pouch or fold of skin along the abdomen, where they are kept until they are able to take care of themselves. This is a singular adaptation, but less specialized and less perfect than the condition found in ordinary mammals.

The movements of migratory fishes are mainly controlled by the impulse of reproduction. Many fresh-water fishes, as trout and suckers, forsake the large streams in the spring, ascending the small brooks where their young can be reared in greater safety. Still others, known as anadromous fishes, feed and mature in the sea, but ascend the rivers as the impulse of reproduction grows strong. Among such fishes are the salmon, shad, alewife, sturgeon and striped bass in American waters. Catadromous fishes, as the true eel, reverse this order, feeding in the rivers and brackish estuaries, apparently finding their usual spawning ground in the sea.

In questions of attack and defense the need of fighting animals of their own kind, as well as animals of other races, must be considered. To struggles of species with those of their own kind the term rivalry may be applied. Actual warfare is confined mainly to males in the breeding season, especially in polygamous species. Among those in which the male mates with many females, he must struggle with other males for their possession. The most notable adaptation is seen in the superior size of teeth, horns, mane or spurs. In the family of deer, buffalo and domestic sheep and cattle the male is larger and more powerfully armed than the female.

A large part of the life of the animal is a struggle with the environment itself. In this struggle only those that are adapted live and leave descendants fitted like themselves. The fur of mammals fits them to their surroundings. As the fur differs so may the habits change. Some animals are active in winter; others, as the bear, and in northern Japan the red-faced monkey, hibernate, sleeping in caves or hollow trees or in burrows until conditions are favorable for their activity. Most snakes and lizards hibernate in cold weather. Some animals in hibernation may be frozen alive without apparent injury. As animals resist heat and cold by adaptations of structure and habits, so may they resist dryness. Certain fishes hold reservoirs of water above their gills by means of which they can breathe during short excursions from the water.

Another series of adaptations is concerned with the places chosen by animals for their homes. The fishes that live in the water have special organs for breathing under water. The hooked claws of the bat hold on to rocks, the bricks of chimneys or to the surface of hollow trees, where the bat sleeps through the day. The tree frogs or tree toads have the tips of the toes swollen, forming little pads by which they cling to the bark of trees.

Among other adaptations relating to special surroundings or conditions of life are the great cheek pouches of the pocket gophers, which carry off the soil dug up by the large shovel-like feet when the gopher excavates its burrow. Insects that live in water either come up to the surface to breathe or take down air underneath their wings, or in some other way, or have gills for breathing the air which is mixed with the water. Many fishes, chiefly of the deep seas, develop organs for producing light. These are known as luminous organs, phosphorescent organs or photophores.

While among the higher or vertebrate animals, especially the fishes and reptiles, most remarkable cases of adaptation occur, yet the structural changes are for the most part external, usually not affecting fundamentally the development of the internal organs other than the skeleton. The organization of these higher animals is much less plastic than that of the invertebrates. In general the higher the type the more persistent and unchangeable are those structures not immediately exposed to the influence of the struggle for existence. It is thus the outside of an animal that tells where its ancestors have lived. The inside, suffering little change whatever the surroundings, tells the real nature of the animal.

A special kind of adaptation is shown by animals which are parasitic. These animals attach themselves to the body of their prey or burrow into it, are carried about by it and live upon it. Some parasites are adapted to an external parasitic life, such as bird lice, fleas, ticks, etc.; others are adapted to an internal parasitic life, as is the case in the tapeworm and trichina.

In nearly all cases the structure of the parasite is very simple, much simpler than that of other animals which live free, active lives. This simplicity, however, is not primitive, but results from the degeneration of structures rendered useless by the habit of life. Thus a fixed and permanent parasite possesses no locomotor organs, no special sense organs, no highly developed nervous system, no alimentary system and but a very simple circulatory and respiratory system. Lankester has well expressed the effects of the parasitic habit of life: "Let the parasitic life once be secured and away go legs, jaws, eyes and ears; the active, highly gifted crab, insect or annelid may become a mere sac, absorbing nourishment and laying eggs."

This simplicity of structure in parasitic animals does not, however, indicate that they belong to animals low in the scale of animal life. It is rather the result of a mode of life. This is shown by the fact that many parasites in their young stages are free, active animals, very much more complex in structure than they are in adult life. Lankester's comparison of the life-history of the parasites Sacculina and Lernæacea with that of an active shrimp will illustrate this point.

Compare these with the young stages of a number of shrimp-like animals, viz., Sacculina, Lernæacea, Lepas, Cyclops, Limnetis, some of which lead a parasitic life. The eggs of all develop equally into the recapitulative phase known as the Nauplius, but while the Nauplius of the free-living shrimp grows more and more elaborate, observe what happens to the parasites; they degenerate into comparatively simple bodies, and this is true of their internal structure as well as of their external appearance. The most utterly reduced of these parasites is the curious Sacculina, which infests hermit crabs and is a mere sac filled with eggs, and absorbing nourishment from the juices of its host by root-like processes.

Lernæacea again, which in the adult condition is found attached to the gills of fishes, has lost the well-developed legs of its Nauplius childhood and become an elongated worm-like creature fitted only to suck in nourishment and carry eggs.

In this same group the life-history of the barnacle illustrates a similar degeneration not due to parasitism. This again Lankester describes. Among these pictured Nauplii, all belonging to the great group Crustacea, which includes crabs and shrimps, is one which gives rise to an animal decidedly degenerate but not precisely parasitic in its habits. The egg of the Barnacle gives rise to an actively swimming Nauplius, the history of which is very astonishing. After swimming about for a time the Barnacle's Nauplius fixes its head against a piece of wood and takes to a perfectly fixed, immobile state of life. Its organs of touch and of sight atrophy, its legs lose their locomotor function and are simply used for bringing floating particles to the orifice of the stomach, so that an eminent naturalist has compared one of these animals to a man standing on his head and kicking his food into his mouth.

Were it not for the recapitulative phases in the development of the Barnacle, we may doubt whether naturalists would ever have guessed that it was a degenerate Crustacean. It was, in fact, for a long time regarded as quite remote from them and placed among the snails and oysters. Its true nature was only admitted when the young form was discovered.

Very many other organisms among both plants and animals showing varying degrees of degenerative adaptation might be cited. It should be noted in this connection that degeneration in biology means an evolutionary method of adaptation by means of which plants and animals are adjusted to special environmental conditions; it does not mean weakness, decline, defects and decay in structural and physiological conditions similar to those occurring in human life. There is only a far-fetched analogous resemblance between human degeneration in the usual sense and degeneration in biology which may be called adaptive because as a result of such degeneration organisms are better fitted for life under special conditions. In fact, many naturalists believe that natural selection has often preserved those individuals which because of certain degenerations are better fitted to their life-conditions. Hence adaptive degeneration in biology is a form of evolution, and it is a highly significant fact that some species of animals and plants have been fitted to their special environment by adaptive degeneration.

It should be noted in passing that in animals and plants there is non-adaptive and destructive degeneration that is parallel to degeneration in human life. The effects of disease in weakening and ultimately destroying animals and plants is an example. In all such cases there is no advantage gained which is exactly the case in the physiological, mental and moral degeneration commonly referred to in human life. Obviously adaptive degeneration has occurred in human life, for the human body has dozens of structures like the appendix which have been adapted by a degenerative process.

Some of the most important special plant adaptations are along these lines: nutritive adaptations, adaptations for protection against animals, adaptations for pollination, adaptations for the dispersal of fruits and seeds, and color adaptations for attracting animals. Of the nutritive adaptations the parasitic habit of life in plants which draw their food wholly or partially from another plant or animal, called the host, should be mentioned. The dodder shows an adaptation of this kind. It lives on the stems of other plants, and instead of developing roots and green leaves, with which to carry on the processes of food manufacture, it develops no green leaves but instead a special absorbing organ, the "haustoria," which penetrates the tissues of the host plant from which it obtains its nourishment. There are many plants adapted to this parasitic habit of life; others are semi-parasitic. This is the case with the mistletoe, the false foxgloves and with some orchids.

A curious case of special nutritive adaptation is to be found in carnivorous plants. These plants seem to require animal food and have organs variously modified to obtain it. In the common sundew insects are caught by a sticky secretion which proceeds from hairs on the leaves. When an insect touches one of these sticky hairs it is caught and the hairs at once begin to close over it until it is held fast on the leaf. Here it soon dies and then remains for many days, while the leaf pours out a juice by which some parts of the insect are digested. This digested material is then absorbed, while the undigested parts drop off after the hairs let go their hold. Other interesting adaptations for the capture by plants of insects are to be found in the Venus fly trap, the common pitcher plant and others.

Other modifications have been developed as a means of protection from vegetable-feeding creatures. These are chiefly along the lines of the formation of uneatable tissue, as in the horsetails and rushes, the arming of exposed parts with cutting edges, stinging hairs, prickles and thorns, as in grasses, nettles, cactuses, etc., and the accumulation of disagreeable or poisonous substances in exposed parts, as in the tansy, ragweed, boneset, jimson weed and poisonous hemlock. One of the acacias (Acacia sphærocephala) has an interesting adaptation to attract ant dwellers as a protection from insects and other creatures. At the bases of the leaves there are developed large hollow stipules and at the ends of the leaflets are nectaries. The ants bore holes in the stipules, live in them, find food in the nectaries and offer valuable protection to the plant in warding off its enemies. A large number of plants offer inducements of many sorts to attract ant visitors.

The special adaptations for the dispersal of seeds offer an equally interesting field for study. It is obviously of advantage to the plant that its seeds be disseminated as widely as possible. Sometimes the seeds themselves are modified for dispersal, sometimes the fruit in which they are enclosed and often it is a larger part of the plant. This is the case with the common tumbleweed, a profusely branching plant bearing many seeds which in the fall is torn from its anchorage by the wind and rolled about, scattering its seeds for great distances. Some fruits which are distributed by the wind are provided with wings, as in the maple, elm, ash, etc., while others bear plumes and feathery tufts to enable them to float in the air, as in the dandelions, thistles and others.

Not infrequently the adaptation for seed dispersal is in the mechanical discharge provided for in the structure of the seed-case. In such plants as the witch hazel, violet, wild balsam and others the dry fruits burst with explosive force, throwing the seeds some distance away from the parent plant.

When the adaptations are related to dispersal by means of animals they take the form of grappling appendages, as in the beggar ticks, stick tights, burdocks, cockleburs, etc., of hard seeds capable of passing through the digestive tract unharmed or of attractive and brightly colored fruits whose seeds are undesirable or indigestible. Good examples of conspicuously colored fruits whose seeds are scattered in this way are cherries, raspberries, blackberries, etc.

It will be noted that the color adaptations of plants referred to so far are supposed to relate plants to animals. But aside from these, there are many general and special adaptations in coloring substances, green, yellow and red, which have a physiological value in plant life. These, however, are special problems of botany and cannot be referred to here.

The whole question of color adaptations in plants has in recent years come up for rediscussion. This discussion cannot be given here, but a good idea of the points at issue can be gathered from the perusal of an essay entitled "The Significance of Color" by Professor D. T. MacDougal, of the Carnegie Institute.

In discussing the color adaptations of animals, it is convenient to group them in the following classes: Protective and aggressive resemblances; warning coloration; mimicry and colors displayed in courtship.

The color pattern of animals is often such as to effectually conceal them in their surroundings. Thus tree-dwelling animals are often green in color, as is the case with the tree-frog; desert dwellers are often a mottled gray, while the arctic dwellers are a snowy white. Far more striking, however, than these cases of general color adaptation are those cases of special adaptation in which the animal resembles in color and shape some particular part of its usual environment. Professors Jordan and Kellogg, in "Animal Life," give some good examples of special color adaptation. Among them are the following:

The larvæ of the geometrid moths, called inch-worms or spanworms, are twig-like in appearance and have the habit, when disturbed, of standing out stiffly from the twig or branch upon which they rest, so as to resemble in position as well as in color and markings a short or a broken twig. One of the most striking resemblances of this sort is shown by a large geometrid larva found near Ithaca, New York. The body of this caterpillar has a few small, irregular spots or humps, resembling very exactly the scars left by fallen buds or twigs. These caterpillars have a special muscular development to enable them to hold themselves rigidly for long times in this trying attitude. They also lack the middle prop-legs of the body common to other lepidopterous larvæ, the presence of which would tend to destroy the illusion so successfully carried out by them. The common walking-stick, with its wingless, greatly elongated, dull-colored body, is an excellent example of special protective resemblance. It is quite indistinguishable, when at rest, from the twigs to which it is clinging. Another member of the family of insects to which the walking-stick belongs is the famous green-leaf insect. It is found in South America and is of a bright green color, with broad leaf-like wings and body, with markings which imitate the leaf veins and small irregular yellowish spots which mimic decaying, or stained, or fungus-covered spots in the leaf.

There are many butterflies that resemble dead leaves. But most remarkable of all is a large butterfly (Kallima) of the East Indian region. The upper sides of the wings are dark, with purplish and orange markings, not at all resembling a dead leaf. But the butterflies when at rest hold their wings together over the back, so that only the under sides of the wings are exposed. The under sides of Kallima's wings are exactly the color of a dead and dried leaf, and the wings are so held that all combine to mimic with extraordinary fidelity a dead leaf still attached to the twig by a short pedicle or leaf-stalk imitated by a short tail on the hind wings and showing mid-rib, oblique veins, and, most remarkable of all, two apparent holes, like those made in leaves by insects, but in the butterfly imitated by two small circular spots free from scales and hence clear and transparent. With the head and feelers concealed beneath the wings, it makes the resemblance wonderfully exact. In all cases of this kind the animals are said to be protectively colored.

Special color resemblance sometimes does more than conceal an animal from its enemies; it often assists it to catch its prey. Such animals are said to be aggressively colored or to have aggressive resemblance. The colors of snakes, lizards and frogs are doubtless both protective and aggressive, while those of the polar bear, the arctic fox, the weasel, the wolf, the lion and the tiger are purely aggressive. Poulton, in the "The Colors of Animals," cites some examples of a still more remarkable use of color resemblance. He says:

"Special Aggressive Resemblance sometimes does more than hide an animal from its prey; it may even attract the latter by simulating the appearance of some object which is of special interest or value to it. Such appearances have been called Alluring Coloration by Wallace, and they are some of the most interesting of all forms of Aggressive Resemblance.

"An Asiatic lizard (Phrynocephalus mystaceus) is a good example. Its general surface resembles the sand on which it is found, while the fold of skin at each angle of the mouth is of a red color and is produced into a flower-like shape exactly resembling a little red flower which grows in the sand. Insects, attracted by what they believe to be flowers, approach the mouth of the lizard, and are of course captured.

"The Angler, or Fishing Frog, possesses a lure in the shape of long, slender filaments, the foremost and longest of which has a flattened and divided extremity. The fish stirs up the mud so as to conceal itself and waves these filaments about. Small fish are attracted by the lure, mistaking it for worms writhing about in the muddy waters; they approach and are instantly engulfed in the enormous mouth of the Angler.

"An Indian Mantis (Hymenopus bicornis) feeds upon other insects which it attracts by its flower-like shape and pink color. The apparent petals are the flattened legs of the insect."

While many animals are very inconspicuously colored, or are manifestly colored so as to resemble their surroundings, generally or specifically, many other animals are very brightly and conspicuously colored and patterned. They possess warning coloration. "A very common example of an animal with warning colors," says Poulton, "is afforded by the larva of the Currant Moth or Magpie Moth, which is excessively abundant in gardens. The caterpillar is extremely conspicuous, being of a cream color, with orange and black markings. Altho it belongs to the group of well-concealed 'stick-caterpillars,' it makes no attempt to hold itself in any of the attitudes characteristic of its group. All observers agree that birds, lizards, frogs and spiders either refuse this species altogether or exhibit signs of the most intense disgust after tasting it."

The caterpillar of the Buff-tip Moth and the Cinnabar Moth are also extremely abundant and are good examples of the association of Warning Colors with a nauseous taste. Both of them are gregarious, living in large companies, so that their conspicuous appearance is greatly intensified. The colors of the first-named larva are black, yellow and orange. It feeds on oak, elm, lime, birch, hazel, etc., and the large bare branches which attest its appetite are very familiar sights in autumn. The second caterpillar is colored by alternate black and yellow rings; it feeds upon ragwort in the summer. There is plenty of experimental evidence for the unpleasant taste of both caterpillars.

The conspicuously black-and-yellow banded larva of the common Monarch butterfly is a good example of the possession of warning colors by distasteful caterpillars.

These warning colors are possessed not only by the ill-tasting caterpillars but by many animals which have special means of defense. The wasps and bees, provided with stings—dangerous animals to trouble—are almost all conspicuously marked with yellow and black.

The lady-bird beetles, composing a whole family of small beetles which are all ill-tasting, are brightly and conspicuously colored and spotted. The Gila Monster, the only poisonous lizard, differs from most other lizards in being strikingly patterned with black and brown. Some of the venomous snakes are conspicuously colored, as the coral snakes or coralillos of the tropics.

All these animals with warning colors are described as possessing some quality, a disagreeable taste or odor, stings, hairs, etc., causing them to be obnoxious to other animals that might seize them for food. Poulton says: "The object of warning colors is to assist the education of enemies, enabling them to easily learn and remember the animals which are to be avoided."

Another special kind of color adaptation to be included under Warning Coloration is known under the head of recognition markings. Instead of attracting the attention of enemies, these markings are of use in attracting the attention of individuals of the same species. To this category belong the white upturned tail of the rabbit, the black tip of the weasel's tail and many of the bright feathers in wings and tail displayed by birds in flight.

Certain animals which are without special means of defense and are not at all formidable or dangerous are yet so marked or shaped and so behave as to present a threatening or "Terrifying Appearance." The large green caterpillars of the Sphinx moths—the tomato-worm is a familiar one of these larvæ—have a formidable-looking, sharp horn on the back of the next to last body ring. When disturbed they lift the hinder part of the body, bearing the horn, and move it about threateningly. As a matter of fact, the horn is not at all a weapon of defense, but is quite harmless. The larva of the Puss moth has been often referred to as a striking example of terrifying appearances. When one of these larvæ is disturbed "it retracts its head into the first body ring inflating the margin, which is of bright red color. There are two intensely black spots on this margin in the appropriate position for eyes, and the whole appearance is that of a large flat face extending to the outer edge of the red margin. The effect is an intensely exaggerated caricature of a vertebrate face, which is probably alarming to the vertebrate enemies of the caterpillar. . . . The effect is greatly strengthened by two pink whips which are swiftly protruded from the prongs of the fork in which the body terminates. . . . The end of the body is at the same time curved forward over the back, so that the pink filaments are brandished above the head."

Some of the instances of protective resemblance, warning coloration and "terrifying attitudes" that have been given are sufficiently remarkable, but the phenomena of mimicry are even more surprising. The term mimicry has been reserved for those cases in which an otherwise defenseless animal, one without poison, fang or sting, and without an ill-tasting substance in its body, mimics some other specially defended or inedible animal sufficiently to be taken for it and so escape attack. These instances are especially to be observed among insects. The most familiar example perhaps is that of the Viceroy butterfly, which mimics the Monarch.

The bees and wasps are protected by their stings. They are usually conspicuous, being banded with yellow and black. They are mimicked by numerous other insects, especially moths and flies, two defenseless kinds of insects. This mimicking of bees and wasps by flies is very common, and can be observed readily at any flowering shrub. The flower-flies (Syrphidæ), which, with the bees, visit flowers, can be distinguished from the bees only by sharp observing. When these bees and flies can be caught and examined in hand it will be found that the flies have but two wings while the bees have four.

In addition to the colors and patterns which assist an animal to evade or warn off its enemies or to secure its prey there are also colors and appendages which must have some very different meaning. These appearances are seen in mature animals, and frequently undergo periodical development at times which correspond to the breeding season; and when the two sexes differ, the males are almost invariably the more brilliant. Instances in which the colors of the males exceed those of the females in brilliancy or pattern are many among fishes, lizards, birds, spiders, insects, etc. It is most common among insects and birds. Many of these sexual differences were described in the chapter on Sexual Selection.

However these colors may have arisen, every observer must admit that they are in some way connected with sex. Darwin accounted for them by his celebrated theory of "Sexual Selection." He supposed that the esthetic sense is widely distributed among the higher animals (vertebrates and some of the most specialized invertebrates), and that the colors, which certainly appeal to this sense in man, are not without effect in causing gratification to the animals themselves. This explanation of the origin and meaning of sexual coloring is not accepted by Mr. Wallace, whose chief objection is the lack of evidence that the female has any esthetic preferences at all in the selection of her mate.

Concerning the whole question of the adaptations of plants and animals there is much question to-day. It is thought by many that the strength of the natural selection explanation rests on the logical nature of its premises and conclusions rather than on scientific observation and experiment. Professor Gadow attacks the mimicry theory vigorously, pointing out that there are as many mimicking as mimicked species in given areas. Thayer's coloration theses have been admittedly highly overstated. Professor Kellogg comments on the present status of the theory in its relation to adaptation as follows: "There is no gainsaying to the selection explanation its claim to stand among all proposed explanations of adaptation as that one least shaken by the critical attack of its adversaries. However mightily the scientific imagination must exert itself to deliver certain difficult cases into the hands of selection, and however sophisticated and lawyer-like the argument from the selection side may be for any single refractory example, the fact remains that the selectionist seems to be able to stretch his explanation to fit all adaptations, with less danger of finding it brought up against positive adverse facts than is possible to the champion of any other so far proposed explanation."

Quite naturally, one faces with caution the general summing up of such a mooted question as the validity of Biology as a determining factor in human conduct. Earlier in this volume it has been shown that biological analysis cannot produce a creed and that evolution is neither a religion nor an attack on religion. The biologist desires to know causes, but it is no part of his work to dictate the effect on the mind, resulting from the interpretation of those causes.

The modern biological viewpoint of heredity, indeed, is far different from that of the Middle Ages. No one to-day can look upon Heredity as a Fate outside the organism, granting at pleasure certain gifts and withholding others. Heredity is not a dæmon or an angel, making this man a genius, that a clod; this acorn an oak-tree, that an elm. The acorn will grow into some sort of an oak, the child into some sort of a child of that father or mother—not of any other brace of parents. Heredity is a highly complex mosaic, made up of an incredibly large number of pieces, but it is only made up of the pieces that are there. No new piece is flung in by some craftsman's hand, at the last moment. Whether the design was there from the beginning, or no, is not of biological concern. Many biologists think it possible.

The doctrine holds true in biology that, ill-fated or well-fated, every living creature is born a new creature. The chapters in this volume which deal with variation have shown that discontinuity is as operative as continuity. The result may be a monster, a mediocrity or a masterpiece (with the odds overwhelmingly in favor of mediocrity), but it is impossible that it shall be exactly the same as any other creature. There is unquestioned predestination, in that the path is largely marked out by heredity and environment, there is unquestioned free will in the fact that the personality is composed of different strains in the heredity and has a different aspect of correspondence to the environment.

The greatest master among the early writers on Natural Selection, Darwin's generous ally, was far and away the leader of the naturalists who could not agree in regarding Man as a natural product of the processes of development. Wallace did not believe that the known factors were sufficient to account for Man's higher qualities, for his artistic and moral faculties, and he concluded that these must have had another mode of origin, far removed from what are known as the "normal evolutionary processes." He regarded these as things apart, to be considered from another aspect, and stated in point blank terms that "we can only find an adequate cause in the unseen universe of spirit." He said the same in regard to the origin of life and the emergence of consciousness.

Professor J. A. Thomson and Professor Patrick Geddes, however, tho both notable for their deep reverence in the handling of scientific matters, take sharp exception to Wallace, declaring that there is absolutely no ground for supposing that the process of life-development which has been shown to progress continuously from the Protozoon to the Mammal, should suddenly come to an end. To say that the artistic and emotional faculties of man cannot be the result of this same process is, they affirm, "giving up the fight too easily."

"Like any other science," say Professors Thomson and Geddes in their essay in "Ideals of Science and Faith," "Biology has for one of its ideals the aim to gain a clear, orderly, correlated and interpretable view of Nature. It analyzes and pulls things and systems to pieces, but only as a means to an end, in order sooner or later to put them together again, unified in intelligence. By it, many a chaotic corner is acquiring a semblance of rational order, many a puzzling obscurity has been illumined, many unsuspected linkages, correlations and affiliations have been discovered."

There is no doubt that the universe shows a greater coherence than it did. No longer does the world seem like a multiverse, composed of dissonant factors, but it chords like a universe. Science has set aside the old conflict between two warring supernatural factors, Good and Evil, and shown that all things work together for good. The extraordinary kaleidoscope which we know as animate nature or organic life is seen to be a true kaleidoscope, that is to say, it is made up of marvellously complex patterns from comparatively few pieces, mirrored, and remirrored in a thousand aspects. Life is not a relation of scattered entities; it is one entity which is extremely difficult to see as a whole. Even Biology does not give the whole. It only links up, piece by piece, some of the earlier and younger of its chapters.

The biologist has no right to regard himself as the dictator of a realm of thought. It would be arrogance to say that because he knows the fission-plans of a cell, he can therefore demand that the education of all children must be put into his charge. Cell-fission is a necessary part of the individual, but it is a minor factor of the whole. The picture of the world is vast and much of the canvas is blank.

The biologist fills in one corner. What the whole picture will reveal is beyond his ken. He cannot step back off the world far enough to see it in its entirety.

None the less, Biology has an emotional aspect, and here again, Professors Thomson and Geddes have expressed the feeling with great care and value. "This world is not a stony sphinx," they say, "but a throbbing life, which to know is to love. The man of dominantly scientific mind . . . cannot help feeling all the time that he is working at a picture which will not only inform, but gladden the eyes. . . . Science, like a child pulling a flower to bits, is apt—and Biology is one of the worst of the offenders—to dissect more than it constructs, and to lose in its analysis the vision of unity and harmony which the artist has ever before his eyes.

"Perhaps, however, if the artist has patience, he would often find that science restores the unity with more significance and more beauty in it than it had before. As Biology passes from the structural (the morphological view) to the functional (the physiological one), as it escapes from the static to the kinetic, as it returns from the formal to the vital . . . it condones its destructive analysis by showing that things are more wondrously, beautifully, intensely alive than even Pan-zoism suspected. . . . The general result and ideal of Biology is to deepen our wonder in the world, our love of beauty, our joy in living. The modern botanist is in a very real sense more aware of the Dryad in the tree than the Greek could be. Biology, by its revelation of the mystery, wonder and beauty of life, its intricacy and subtlety, its history, its tragedy and comedy, approaches another aspect of the Idea of God."

No man can step off his own shadow, and this is a work-a-day world. To justify itself, especially to Americans, Biology must show strong practical aspects. Knowledge for the sake of knowledge is as false and hurtful a philosophy as "Art for the Sake of Art." Knowledge for the sake of human betterment is a far truer standard.

That Biology is increasingly commanding the highest attention and respect, nay, more, that it is securely establishing its place as a foundation stone to all other sciences, is manifest. As the bedrock of life, it is the bedrock of all things with which life has to do, and, since we are living beings, it is the bedrock to ourselves. Its contributions to health and disease, to sociology and all the various aspects of religion, become daily more evident and lead by direct paths to the highest of all culture, the Culture of Life. As Life is fundamental to knowledge, so the Culture of Life is fundamental to the Culture of Knowledge, and there is many a riddle as yet unread for which Biology alone, in time to come, will be able to give the key.

ZOOLOGY

INTRODUCTION

UNDER favorable conditions, the study of animal life becomes not only profitable to mankind, but also as musical as Apollo's lute. To know the animal life of the world is to know the world. It is impossible for an intelligent mind to grasp the principal animal forms of a given country without at the same time acquiring a great store of knowledge of that country's topography, soil, climate and people.

The love of wild life springs eternal in the human breast. It is as natural for every child to be interested in animals as it is for every child to love the sound of music. Sad to say, however, that natural love for zoology often is completely stifled, or warped out of shape, by lack of opportunity. Those who by force of circumstances are compelled to grow up and live out their lives without knowing the satisfaction that is derived from an intimate acquaintance with at least one section of animal life, lose much pleasure to which they legitimately are entitled.

At no time in the history of the world has zoological knowledge been so vitally important to mankind as it is to-day. As animal life rapidy diminishes, its economic value to man becomes more apparent. Fifty years ago the edible fishes, lobsters, oysters and clams were so abundant that no one found it necessary to delve deeply into the life history of any one of those groups. To-day, and for the future, only the most careful conservation and cultivation, based on precise zoological knowledge, can preserve to man a continuous supply of those valuable and delicious foods.

For twenty-five years the nation and the States have been studying ichthyology earnestly and diligently, in pursuance of their costly and toilsome efforts to keep up the great food supply of the poor—the edible fishes. The demand in the United States for a flesh-food supply that is cheaper than mammalian meat now engages the efforts of more than 200,000 men, backed by $60,000,000 of capital; and the animal fish product has a value of about $50,000,000. Each year about 1,400 million fish eggs and live fishes are distributed by the United States Bureau of Fisheries. Verily, ichthyology is something more than a mere pastime for the angler or the student. To-day it is on the same basis of human necessity as is the growing of wheat and corn.

Fifty years ago few persons in America gave thought to the study of insects, save as a pastime. During recent years the ravages of insects have called forth a grand army of entomologists, first to study the destroyers, and then to fight them. To-day every farmer and fruit grower, every forester and every park superintendent is engaged in the great irrepressible conflict that is being waged between Man and the Insect World for the possession of the fruits, the vegetables, and the trees that are as necessary to this earth as is the air we breathe. The monthly bulletins of the State Economic Zoologist of Pennsylvania painfully bring home to us the appalling extent and the fierceness of the battle for the trees. Verily, the study of entomology has come to us to stay.

For twenty years the United States Government has been engaged in a continuous effort to inform all the people of the United States that the wild birds are man's most valuable friends and allies in his warfare against insect and mammalian pests.

Some communities hearkened gladly to the message, and responded with reasonable promptness to the efforts of the bird lovers in behalf of protective bird laws. A few States remained hostile to bird laws until the cotton-boll weevil and other pests sharply brought home to their people the fact that they needed the assistance of the birds.

Now that man's heedless and ignorant destructiveness has accomplished the extinction during our own times of a score of important animal species, and to-day is threatening to annihilate many others, zoological knowledge has suddenly become a practical necessity. Both to the statesman and the citizen the protection of wild life has become a solemn duty. Ignorance is dangerous alike to our forests and streams and to our wild life.

The time has long passed wherein it was necessary to justify by argument the existence of museums and the study of zoology. The nature-study courses in our secondary schools testify abundantly to the public recognition of the need for the dissemination of zoological knowledge.

Unfortunately, however, the workers in that field are as yet blindly groping for the methods by which they may impart to the school pupils of America the precise and practical animal lore that they need and desire. To-day the nature-study teachers elect to relegate to the background the great System of Nature in favor of a few actual objects in the classroom which the pupil can handle and dissect, and use as a foundation of original pupil philosophy. But the case is not wholly hopeless, for the present situation is so bad that it cannot long endure.

After long and unsatisfactory contemplation of study courses that mix together all sorts of living creatures in one chaotic mass, it is a pleasure to take up a scholarly work in which the methods of Nature are fully recognized and clearly set forth. Herein the foundation stones of Nature are assembled, and well and truly laid.

Fortunate is the young naturalist, and likewise the general reader of animal lore, who early acquires the habit of broad generalization. I am tempted to call it the bird's-eye-view habit. Had I but one chance to send a message to the young naturalists of the world, that message would be this: Lay out for yourselves a broad foundation of systematic knowledge, and after that each stone of the structure will find its own permanent place as joyously as running water seeks the lowest level.

It is impossible to insist too strongly upon the absolute, vital necessity of confronting all zoological studies with the great system of Nature. He who attempts to study any small group of animal forms without first gaining a bird's-eye view of the surrounding territory, and becoming familiar with the zoological grand divisions that lie around him, loses much. It is a mastery of the grand divisions —the orders, families and genera, in particular—that lends the greatest charm to the study of zoology. The librarian who expects to store ten thousand books in such a manner that each one may be instantly available, wisely provides twenty-five alcoves and two hundred and fifty shelves; and thereafter each new accession of books is a source of joy, because the place for each volume is ready. The young naturalist without a zoological foundation is like a librarian who has no shelves and must create a place for each new book.

But, after all, systematic zoological arrangement, or "classification," is only to be regarded as a ready means to the accomplishment of more important ends. To-day the world is keenly concerned in the philosophy of animal life, its whys and its wherefores. A well-thought-out exposition of the origin and relationships of animals offers an excellent foundation for studies of species, and of the habits and mental processes of individuals, that shall continue and furnish human interest as long as any wild life remains upon the earth.

The old question, "Where does the animal belong?" has now as a running mate the ever-present query, "What does it think and do?" The latter offers to every intelligent human being a delightful field of study and research. The new question, "Do animals reason?" is no longer a question, save with a very few persons to whom the animal kingdom is mostly unknown territory. All the men who are best acquainted with the living wild animals of the world assert, as one man, that all animals think and reason; that some think very little, others much; and that some animals have reasoning faculties that are superior to those of some men.

During recent years the work of our paleontologists has been profoundly fruitful. In America the rocks of the Western bad lands have yielded an extinct fauna of a character so marvelous as to be almost incredible until the actual remains are seen. It is quite beyond the power of words to convey adequate conceptions of the reptilian giants that formed the group of dinosaurs. The Brontosaurus, the Diplodocus, the Triceratops, the Stegosaurus and the Tyrannosaurus all must be seen in order that the wonders of them may be appreciated.

The story of the Jurassic Age in North America, as told by those gigantic remains, is sufficient to awe the most frivolous mind.

In the presence of those vast skeletons, some of them so colossal that even the largest elephants of the present day seem small, the thoughtful observer finds a new realm of knowledge opening before him like a panorama. The animal kingdom takes on a solemn dignity and vastness never known before. Naturally, the mind reaches out, octopus-like, to fasten tentacles upon the Past and link it to the Present.

There is one result of zoological knowledge that no man can adequately set forth in words. It is the unending satisfaction, and at times the delight, that comes throughout the journey of life to every person who is able to recognize the most important animals that are met by the way. Except in mid-air, it is well-nigh impossible for man to travel so far that he leaves behind him all visible forms of animal life. I believe this has been accomplished only by the men who have pressed nearest to the poles, through the utmost cold. He who knows the wild animals of the world always travels among friends, and in every land he finds a welcome. To him the whole world is interesting. To his pleasure in life thousands of beasts, birds, and creeping things contribute. Nature's multitude of interesting forms stimulate his efforts to acquire knowledge, and her fields of research come the nearest to revealing the fountains of perpetual youth.

To-day, the life of the ardent nature lover is filled with activities. On the one hand there is the balance of Nature to preserve, and on the other that lost balance is to be restored. Those who are not engaged in fighting the noxious forms of animal life are commonly found on the firing-line of the army that is fighting the perpetual war with those who would, if let alone, exterminate all wild creatures from the whole earth. Let us hope that millions of intelligent Americans will learn to appreciate more fully the splendid fauna of this continent in time to save it from the forces that now threaten it with annihilation.

William T. Hornaday.

ZOOLOGY

CHAPTER I

ZOOLOGY IN FABLE

The beginnings of Zoology lie in the region of fable. In the earliest traditions and myths of primitive races the world is peopled with men and animals, some real, some half-real, some entirely fabulous. Natural and supernatural are mingled together and a religious or superstitious significance attaches to both real and unreal beings seen or imagined by primitive man. His ready imagination and uncritical belief made the creations of his fancy seem as real as those of his observation and experience. With the increase of knowledge of the real, the unreal became more and more relegated to the domain of folk-lore and fable. Some of it had been preserved in the traditions and myths of different races, some crystallized in the fanciful animals of decorative sculptures, paintings and heraldry. Most of it has been forgotten.

It has been well observed that the imagination of man does not really enable him to create anything new, but only to recombine or rearrange what he has seen. He may combine the body of a reptile with the wings of an eagle; he may combine the head and shoulders of a man with the body and legs of a horse or attach to a human form the white wings of a swan. He may in fancy enlarge a mouse to the size of an elephant or conceive of a serpent large enough to encircle the whole world; he may support the universe upon the back of an elephant of appropriate size. But all these are not new creations; they are objects known to his experience, but recombined or altered in proportions. It is only as he comes to realize with wider knowledge that certain combinations of parts, certain relations of size do not occur in nature, that these imaginary beings become improbable or impossible. He is accustomed to supply the missing parts of half-seen animals from his previous observations. He sees the head of a deer projecting from the leafy wall of the forest and all unconsciously pictures the rest of the quadruped from what he has seen before; he sees a distant eagle perched upon a crag and knows well enough that when it starts to fly it will stretch out a pair of broad wings now closely folded against the body and invisible in the distance. If then he sees dimly outlined in the clouds a human form, what more natural than to supply it with the long feathered wings that belong to the birds of the air, or if at night with the wings of the bats that infest his cave dwelling? Nearly all of the fabulous monsters of zoology belong to this early period. They have been handed down conventionalized in form and degenerated into fable, but originally they were just as real as the rest of the half-seen, half-imagined world in which primitive man existed.

Perhaps the most familiar and universally known of these fabulous animals is the dragon. It appears in all the older myths of the Western nations in serpent form, usually winged, often with fiery or pestilential breath, the deadly enemy and scourge of man. It is equally prominent among the Eastern peoples, and probably received from them its conventional form, the long hind legs, the great eagle claws, the body covered with glittering armor scales, the writhing tail and bat-like wings. Among the Mediterranean nations it appears first as a sea monster and comes up out of the sea; wings were a later addition. In the Northern myths it is at first a "worm"—*i.e.*, a serpent of gigantic size—and the conventional form is borrowed later from the East.

The fabulous Dragon had a real counterpart, singularly close in some respects, in the extinct carnivorous Dinosaurs of the Age of Reptiles. These gigantic reptiles were not winged, indeed, but in the proportions of body, limbs and tail, in the huge head and sharp teeth, the enormous, sharp, eagle-like claws, possibly even in the glittering scaly armor, some of them at all events might have sat for a very tolerable portrait of the dragon of mythology. It is a tempting explanation to suppose that some tradition of these real monsters, handed down from primitive ancestors, was the basis of the dragon legends so widely scattered among all races of men. But this theory must be regretfully abandoned when the perspective of the geologic record is examined. The last of the Dinosaurs became extinct at the end of the Cretaceous Period, some three million years ago at a moderate estimate, before the evolution of the various races of modern quadrupeds had begun, long before monkeys and apes had evolved out of the primitive lemur-like animals from which they are derived and long, long before the evolution of man. The remote ancestors of the human race in the days of the Dinosaurs were tiny shrew-like animals, inferior in intelligence to almost any living quadrupeds, and millions of years were to elapse before they slowly evolved a higher intelligence and finally became capable of articulate speech. So it is utterly impossible that a tradition could have been handed down from the time when Dinosaurs really existed.

Nor is it to be supposed that the dragon myths are based upon discovery of their fossil remains, for in the millions of years that have elapsed since their time the sand and mud in which their remains were buried have been converted into hard sandstone and shale and the bones so thoroly petrified that they appear much like the rock itself. They would not easily be recognized as bones at all, and it would be quite out of the question for primitive man to get any correct notion of the kind of animals they represented if he happened to come across a few fragments unearthed out of the rock. Dinosaur bones might conceivably pass for bones of giants, but the concept of the dragon could not possibly be founded upon them. There remains a third explanation, that in some region of the world Dinosaurs might have survived until more recent times and have been seen by primitive men. But from what is known of the geological history of life, this supposition is so exceedingly improbable as to amount to an utter impossibility. One is obliged to conclude that the dragon is wholly a creation of the imagination of man, its source being probably among the races of Eastern Asia. How and why it came to assume its present conventional form would require a broad knowledge of the early history and mythology of these races to discern.

In the traditions of the Northern races the dragon legends are engrafted upon the myth of the giant serpent, the "Worm," which in the old Norse story encircles the earth, lying at the bottom of the surrounding ocean. This same myth, in another form, is handed down as the Sea Serpent. Sea serpents, however, are easier to credit than dragons, partly because less is known about the inhabitants of the sea than those of the land, partly because among the multitudinous forms of ocean life there are many that correspond more or less with the preconceived idea of what a sea serpent ought to be like. So that while the dragon is confined to the legend and no one professes to have really seen one, there be many, down to the passengers on modern ocean liners, who have testified to seeing a sea serpent of approved type. Sometimes it may be one of the large sea snakes, sometimes a ribbon fish or a school of porpoises following one another as they leap out of the water so as to give the impression of the rolling coils of a great serpent. Sometimes a long streamer or tangle of seaweed may look like the giant serpent with its maned neck which all expect to see. Possibly among the unknown inhabitants of the great deep some such animal may really exist. But until it is captured and its remains deposited in some museum of natural history it must be ranked among fabulous monsters.

The Unicorn of classical writers was a real animal; the great one-horned Rhinoceros of India, well known to Eastern writers and not unfamiliar to the patrons of the Greek or Roman circuses. In medieval Europe it suffered a curious transformation. The Northern artist had never seen a rhinoceros nor talked with any one who had. He knew that it was a great four-legged beast with a long horn on its forehead and the traditional foe of the lion. So he grafted the twisted tusk of a narwhal on the forehead of a horse and in this form it was conventionalized in heraldry, its source not recognized when, centuries later, the rhinoceros was reintroduced to the knowledge of Western nations.

The various composite monsters of the mythology of different races—the Centaurs and Sirens of the Greeks, the Mermaids and Swan-Maidens of Western Europe, the winged bulls of Assyria or the eagle-headed gods of Egypt—have all a more or less definite religious significance and are theological rather than zoological myths. Some of them have survived in zoological lore, supported, like the sea-serpent, by the occasional sight of animals more or less resembling what the observer expected to see and their described appearance colored by the traditional description. Mermaids appear every now and then in the accounts of medieval writers; some of the stories may well have been based on the manatee or dugong, while in more recent years actual specimens of stuffed mermaids, manufactured by the ingenious Japanese from the fore part of a monkey and the tail of a fish, have often been exhibited.

To another class of zoological myths belong the innumerable fanciful stories told of the characters and habits of real animals; of the transmutation of men into animals and vice versa, and of the transformation of one species of animal into another. Real metamorphosis of form, as of the tadpole into the frog or of the larva into the perfect insect, is well known to modern natural history, but however much or little a primitive ancestry may have known about it, there seems to be no good reason to believe that the enchantment-transformations of mythology originated in any real observations of metamorphosis in nature. Dream experiences imperfectly separated from the recollections of waking hours had probably much to do with their conception. Hence it would seem that while Natural History possesses relations which may throw its beginnings to the fabulous monsters of ancient times, the same cannot be said for the Science of Zoology, which as a science requires evidence, and having classified that evidence is loth to admit therein such mythical creatures who are undoubted aliens.

CHAPTER II

DEVELOPMENT AND DISTRIBUTION

The animal kingdom includes a vast variety of organisms whose common basis of life is the cell. They are, like plants, an organized community of cells. The various members of this community are adapted to perform different services, and many groups have specialized, each for its particular function, so that the individual cells are no longer capable of a separate life. The animal or plant is thus not a mere aggregate of living cells, but an organism. In the successive classes and orders of animals, from lowest to highest, there is a progressive complexity in the organism, a more and more absolute and exact limitation of the cells or groups of cells to special functions. This progressive specialization is the key to the life history of the individual organism, the development or "ontogeny" of the animal; and to the life history or "phylogeny" of the race.

All animals are to be regarded, then, as organized communities, the units of these communities being protoplasm cells, originally identical in structure and capable of all the necessary activities of life, but specialized to perform particular functions. The first steps in the plan of organization as they appear in the development of the individual are identical in all animals.

The cell divides and re-divides until it forms an aggregate of numerous small cells, the "blastula." This aggregate, continuing to subdivide, then takes on a thimble-like form, "gastrula," one layer of cells lining the cavity, the other being external. This cavity is primarily to contain and digest food, and the cells lining it naturally take on the functions of nutrition, while the outer cells, in contact with the outside world, take on the functions of sensation, of offense and defense, and procuring food. The living sponges and hydroids illustrate this stage of development, more or less modified.

The next important stage in development is the formation of a third intermediate layer of cells between the inner layer or endoderm and the outer layer or ectoderm. From this intermediate layer are developed in the higher animals the muscles, circulatory system and various glands and organs, the alimentary system with its glands being developed from the endoderm, the skin, the nervous system and the organs of sensation from the ectoderm. From this point onward, fundamental differences are to be found in the plan of organization of the principal types of animals and the organs, adapted to serve the same purposes, are often developed from different parts and in a different manner. It is upon these fundamental differences in organization that the classification of the animal kingdom is based.

These lower animals are derived from the same stock as the higher ones. They persist to-day because they are perfectly adapted to their habitat and mode of life, or because they had gotten into a groove of evolutionary progress which did not allow them to advance so fast or so far as the higher types, or because of arrested development from obscure causes. Some of the factors which have limited their evolution are clearly seen, others are and perhaps always will be difficult to trace.

Life originated in the ocean, or at all events in water; but the dry land environment has stimulated a higher development, the obvious cause being the more abundant supply of oxygen, admitting of more active life. In order to preserve the form and relations of their parts, all animals of any considerable size have been compelled to develop a rigid framework or skeleton of some kind; the material and position of this skeleton, and its further use for purposes of offense and defense, have profoundly influenced the further development of the race. In the lower animals the skeleton is generally external; and the insects may be considered as representing the highest possibilities of a development based upon an external skeleton. In the vertebrates the skeleton at first was mainly external, but this became gradually replaced by an internal structure; and the higher possibilities of development with the internal skeleton form one leading cause for the higher development and greater size attained by vertebrated animals.

The third and perhaps the most important factor in causing or arresting advance in life is in the nature of the environment, whether constant from age to age, or subject to slow secular or periodic change during geological time. If an animal is fitted to its mode of life and the conditions of its immediate surroundings remain unchanged, the organism has no occasion to vary, and tends to become fixed and unprogressive. But if the conditions are slowly changing, the race must become adapted to fit its new environment, and will retain or acquire a variability which through the influence of selection will lead to greater progressiveness.

The uniform and unchanging conditions of the deep sea have not been favorable to progress; the theater of development for marine organisms has been the ever-changing littoral region, the shores of the ocean, advancing and retreating through successive geological periods, widely varied in character, ranging from rocky coasts to sandy shoals, or from muddy flats to the still, clear water of protected inlets. Some of the deep-sea organisms, such as protozoans and sponges, have remained unchanged, so far as is known, from the earliest geological periods down to the present day. Others, like the crinoids, or sea-lilies, long since extinct in the littoral region, have found in the ocean depths a refuge where they still survive. Others again, like the deep-sea fishes, originally adapted to the life of the shore, have become curiously modified to suit the conditions of the ocean's depths.

Easily evident, likewise, is a corresponding difference between fresh-water and land animals. There can be no doubt that all terrestrial life was ultimately derived from an aquatic ancestry; those animals which have solved the problem of the utilization of the more abundant oxygen supply of the air instead of the limited amount available in the water having been able to assume a higher development and greater progressiveness, and the snails among mollusks, the insects among arthropods, and the reptiles, birds and mammals among vertebrates are the highest types in their respective classes. The fresh-water animals, more limited in possibilities of development, and subject to less change and variation in their conditions of life, are of inferior type, and as in the deep sea, among them may be noted survivals of very ancient and primitive organisms and higher types developed upon the land, but readapted to aquatic life. Having once acquired the capacity to use the oxygen of the air, however, they are careful not to lose it again, and remain air-breathers, however far their adaptation to aquatic or marine life may be carried in other respects.

It will have been noted that reference has been made to the ancient forms of life, thousands of varieties of which passed out of existence long before the existence of Man, and it is natural to ask by what means their nature is learned. To reply "By fossils" without determining what a fossil is would be to beg the question. The term fossil, which originally meant merely things dug out of the ground, has come to have a much more definite and restricted meaning in the language of modern science. Fossils are the remains of animals or plants or indications of their former existence, found buried in the soil or enclosed in the rock.

In general, only the hard parts of animals are preserved, the shells of mollusks and crustaceans and the bones of the vertebrate animals, while the fact that they are preserved at all is due to a combination of favorable circumstances. Usually when an animal dies, the flesh or soft parts decay or are devoured; the hard parts last longer, but gradually disintegrate into formless dust or mud under the influence of the atmosphere or the air-bearing waters of the surface. But if the animal is buried in a swamp, a river bottom, lake or estuary, where sediment is being piled up by the action of the rivers or of the sea, its hard parts may be covered up in time to escape destruction and get below the zone of atmospheric influence. In this case the remains will be subject only to the influence of the mineralized waters that permeate the soil and rocks beneath the surface.

The action of these waters is to dissolve particle by particle the organic matter of the fossil, and to replace it with mineral matter. In this process, known as petrifaction, usually the structure is preserved, as well as the external form. The bone or shell is thus converted wholly into stone, solid and permanent like the sediment in which it was buried, now converted by the same agencies into rock. This is the ordinary process by which fossils are made. There is nothing mysterious about it—it is merely the natural result that water seeping upward toward the surface, loaded with mineral matter and destitute of organic matter, tends to dissolve any organic matter it finds on its way and deposit mineral matter in all the minute cavities left, until they are filled and the porous mud or sand becomes solid impermeable rock.

Fossils, then, preserved in this manner, constitute the record of the history of life on the earth. It is an incomplete record. Long periods of time are unrepresented, because the sediments then deposited have been washed away or deeply buried, or the fossils in them destroyed by crystallization. A large portion of the past life of this planet is imperfectly recorded or altogether lost because the animals had no hard parts to be preserved. The vast majority of the records are undiscovered or inaccessible because they are still buried far beneath the surface, and, moreover, the interpretation of the records is often doubtful.

Yet the importance of paleontology, or the study of fossil remains, is great, and its teaching positive because the evidence is direct. No one to-day would venture to question that the fossils of the rocks are the actual remains of animals which lived and died in former ages; and the scientist's knowledge of existing animals and plants is now complete enough for him to be able to declare positively that the animals which formerly inhabited the world were different from those of to-day, and that in proportion as research is pushed backward in time, the earlier forms were more and more diverse from their modern successors. Furthermore, it is seen that the lowest and simplest groups of animals were of the earliest introduction to the past life of the world, and that the higher groups have successfully appeared in order of their complication and specialization in physical and mental structure.

Throughout the geological record there is evidence of "annectant" or intermediate types, linking together groups of animals now widely separated; and the earliest appearing members of each group are more or less "generalized," that is to say, their bodily structure conforms to the general type of the whole group, but shows a combination of characters which are now found scattered among the various modern members of the group, but seldom or never all combined in one animal. These generalized characters also are apt to be annectant, and link the group to other groups.

For example, the birds and reptiles are now wide apart, the birds being toothless, feathered, adapted to flight, walking or hopping when on the ground, and with the tail (exclusive of feathers) reduced to a little rudimentary stub, while the reptiles possess teeth and scales, and are crawling or swimming, with long vertebrated tails. But all the earliest birds had true teeth like reptiles, and the oldest of them, the Archæopteryx, a long vertebrated tail feathered on the sides like the head of an arrow. And on the reptilian side are found the Dinosaurs among the more ancient reptiles resembling birds in many details of their bony structure, and especially in their long legs, adapted to walking instead of crawling; and the Pterodactyls, a group of flying reptiles, the latest of them tailless and toothless, with horny beaks like the birds.

Again, there is a great gap among modern animals between fishes and four-footed animals of the land. But the most ancient fishes are precisely those which come nearest in structure to the higher vertebrates, and from which these might most readily have been derived. Through all the invertebrate groups the same conditions appear.

Thus in a broad way the discoveries of paleontology tend continually to break down the sharp lines of distinction between the great modern groups and classes of animals, and do so in just such a way as must follow if modern theories of zoology be true.

If the various species, genera, orders and classes of animals are derived from a common ancestry through the developmental process it should be possible to trace the successive steps in the progress and differentiation of each race by the fossil remains of its ancestral stages in the successive geological epochs. This has been done, precisely and in detail, in many instances; that it has not been done in all is due to the imperfection of the geological record, to a peccable knowledge of it, and especially to the vastness of the problem and the limitations, in means, facilities or insight, of those who are laboring to solve it. Broadly and approximately, the course of the advance of animal life has been traced out from the indirect evidence of structure and individual development, and the more direct but less complete evidence of paleontology. The task of working out and proving it in detail is as yet far from complete. But among the thousands of workers who are devoting their lives to the study of fossils and their meaning, it must be admitted that there are few who find cause to lead them to doubt the theory of descent. Difference of opinion among scientific men to-day is almost exclusively as to the method, not as to the fact.

Closely allied to the nature of the animals of the past is the question of their habitat in early times, involving the problem evoked by their present geographical distribution. This has become almost a science by itself.

There are very few species of animals which inhabit more than a portion of the world; most of them are limited to quite a small part of the land or water areas. Man is perhaps the most cosmopolitan of all land animals. He inhabits every considerable land area of the globe, except the antarctic continent and a much smaller area around the North Pole. Most animals, however, are limited in their distribution by uncongenial climate or by barriers which the species has not found means of crossing. With land animals these barriers may be broad stretches of ocean, extensive deserts, high mountain ranges, or great rivers. With sea animals they may be continental barriers, uncongenial stretches of coast, and sometimes the volumes of fresh water poured out by great rivers. But the limitations imposed by climate and temperature are efficient barriers to world-wide distribution.

Animals are dependent directly or indirectly upon plants for their food, and the abundance and rapid growth of vegetation in the tropics affords opportunity for a corresponding development of animal life. The profusion and variety of life in the tropics cannot fail to impress an observer from the temperate zone. The struggle for existence everywhere going on is perhaps somewhat different in character. It is an internecine war, a strife for survival among the animals themselves rather than a combat against an unpropitious climatic environment. In the temperate and especially in the arctic regions the element of struggle against the untoward conditions of outside nature is superadded to the ever-present war against other animals, which, scattered over a wider space, is less apt to impress the observer, altho its influence on the development of the race may be no less powerful. Here, perhaps, in the double struggle—against animals and against nature itself—lies the reason for the dominance of temperate and northern types when brought into competition with the more abundant but less severely selected races of the tropics. This fact is familiar in the case of man, but is equally true among animals. The tropic regions, with their abundant food and easy life, are the refuge of inferior races, succumbing and driven forth before the sterner competition of the north.

The zoological realms and provinces of the world correspond broadly with the geographic divisions, and even to some extent with the political divisions, since geographic and climatic barriers have conditioned the distribution of the races of men and thus largely influenced their governments. In the land fauna it is observed that the great land mass of the northern continents forms one great zoological realm, the Holarctic; South America a second, the Neotropical; Africa south of the Sahara a third, the Ethiopian; and Australia a fourth, the most isolated of all. The various islands partake more or less of the character of the mainland adjoining, but there are marked differences which point to a different distribution of land and water in former times than now.

Thus the animals of the British Islands are almost identical with those of Continental Europe, while the animals of Madagascar are widely different from those of Africa. The simplest explanation, obviously, is that the former have been connected with the mainland of Europe since the present species of animals came into existence, the latter has been separated from the mainland since remote ages. Geological considerations support this view.

The marine provinces correspond in part with the great oceans, but are more influenced by zones of temperature than those of the land. So far as shore animals are concerned, their lines of distribution will be along the coast lines, and a broad area of deep sea is as much a barrier to most of them as is a land barrier. Like the land animals, however, they give convincing evidence of former differences in the distribution of land and water. There is a considerable proportion, for instance, of identical species on the two sides of the Isthmus of Panama not found on the Asiatic or European coasts. Hence there must have been communication between Atlantic and Pacific oceans, either at the Isthmus of Panama or elsewhere, since these species came into existence. They could not have gone around the Horn, because they are tropical species and are not found on the shores of temperate South America.

The geographic distribution of animals, present and past, together with the geological record of the life-history of each race, furnishes a most important line of evidence on the past history and geography of the globe, and under the name of "paleogeography" a branch of study is being built up which is of great scientific importance as well as of transcendent interest. Its scope and vastness of purview are readily recognized when it is remembered that an intimate knowledge of Zoology and Geology (each of them vast and comprehensive) is a prerequisite. Especially is this true of the lower orders of life, which, despite their simplicity, afford the most fascinating realms of investigation.

CHAPTER III

THE LOWER INVERTEBRATES

From the earliest times, when Sponges were believed to be but solidifications of the foam of the sea, they have been an element of curiosity to Man. They have been declared to be animal, to be vegetable and to be mineral; ancient naturalists quarreled over the question whether they could move or no, and Aristotle's decision that they were animal because they shrank when moved from their rock bases provoked a storm of dissent. Even so keen an observer as Lamarck believed the apertures on the surface of a sponge to be the mouths of small cells inhabited by polyps, and he expended no little wonder over the question why a polyp never was to be found in his cell. Peysonnel, on the other hand, declared that sponges were created by a giant sea-worm, and held that the sponge itself was "mere nidus and excretion."

It is now known, however, that the ordinary sponge of bathtub importance is the horny skeleton of one of the simplest kinds of animals. In life this horny framework is lined with an inner and an outer layer of cells. It is fast to a rock or coral block; its movements consist only in inducing a current of water through the pores by means of tiny whip-lashes attached to the inner cells, and by a certain amount of contraction and expansion of the entrances to the pores. The cells absorb and digest any food matter that is brought by the currents of water passing through the pores. Most of the growth is by budding; bisexual reproduction does occur, however, alternately with the giving off of gemmules, or independent buds; these gemmules, produced in the autumn, develop into male and female forms, and the ova from the one, fertilized by spermatozoa from the other, give rise to a summer generation of sponges, which in turn produce gemmules. This alternation of generations is not uncommon among lower animals.

There is a great variety of sponges, some with a calcareous skeleton, others with horny or siliceous skeletons. They are nearly all marine, and the best known kinds are tropical. The commercial sponges, of which the best come from the Mediterranean and Indian seas, are found in clear water at moderate depths. The fishermen locate them by looking through a glass-bottomed bucket, and pull them up with a pair of hooks on the end of a long pole. They are left upon the shore to die and decompose and then washed and bleached. Among the siliceous sponges some, like the Venus' Flower Basket, are exquisitely beautiful in the form and structure of the skeleton. These live at great depths and are obtained by dredging.

Fossil sponges are found in the most ancient rocks. Professor Cayeux has discovered the spicules of siliceous sponges in the Archaean rocks of Brittany, which would make them the oldest fossils known; and they are common in the oldest fossiliferous formations of other parts of the world. So that the testimony of the rocks appears to confirm what would be expected, that the sponges are the most ancient, as they are the simplest of the Metazoa, or many-celled organisms.

The Corals and Sea-anemones, Hydroids and Jelly-fish, grouped under an order "Cœlenterata," are but little less simple in form. In all these animals the structure consists simply of a body cavity with a fringe of tentacles around the edge. The tentacles are stinging and sensitive cells which serve to capture the food; the body cavity is lined with digestive cells which serve to digest it, and is sometimes partially divided up by partitions extending inward from the outer wall; and the outer layer of cells may secrete a calcareous shell which serves as a protection. The jelly-fish are free-swimming organisms; the hydroids and sea-anemones are fixed to the bottom; and the corals are great colonies of individuals which secrete a calcareous shell.

The translucent milky umbrella-like disk of the jelly-fish, lazily opening and closing as it floats along the tide, is familiar to every one. Beneath the disk hangs a circle of long tentacles, stinging cells which serve to kill or paralyze small fishes or other minute animals that may come in contact with them, and are floated into the body cavity by a current of water produced by the lashing of cilia, or whip-cells, in the same way as in sponges. Many jelly-fish can inflict a sting sufficient to cause severe pain to the incautious hand which touches them. The structure of the stinging tentacles is very curious. A. G. Mayer, in his "Sea-shore Life," describes them as follows: "The long flexible tentacles arise from the side of the bell near the rim. The tentacles are covered with the wart-like clusters of minute thread-cells, each containing a coiled tube which can be turned inside out as we might do with the finger of a glove. If the tentacles come in contact with a small fish or crustacean these little stinging threads are instantly discharged, and on account of their minute size they penetrate the skin of the prey, carrying with them a poison, believed to be formic acid, which quickly paralyzes the victim."

The jelly-fish produces eggs, which, however, do not develop directly into free-swimming jelly-fish, but into fixed hydroids, and these in turn bud off jelly-fish. This is another example of alternate generations. Hydroids differ from jelly-fish in being fixed to the bottom; they are like little vases, the lip lined with stinging tentacles, and many of them develop by budding into compound colonies. Many of the jelly-fish are strongly phosphorescent at night, and swarms of them floating in the water make a very brilliant display when stirred up by a boat passing through or by the breaking of waves upon the shore.

It may seem strange that such an animal as the jelley-fish should leave any traces of its presence in the rocks. Nevertheless, under certain favorable circumstances they may be buried in the sand and converted into siliceous casts without much loss of shape, and these fossil casts, known as "star-cobbles," are found in the most ancient rocks of the Cambrian period in Alabama and elsewhere. So it appears that jelly-fish were among the inhabitants of the seas at the dawn of recorded geological history.

"A sea-anemone," says Mayer, "is a barrel-shaped animal. The bottom of the barrel is fastened to some rock or other firm anchorage, while the upper end bears a slit-like mouth which is encircled by a fringe of tentacles. The mouth leads into a simple tube-like throat, which is bound to the inner sides of the barrel by means of radiating partitions.

"The throat-tube is, however, only about one-half as long as the height of the barrel, so that the radial partitions in the lower half of the barrel cavity do not meet at the center, but leave an open space which is the 'stomach' of the anemone. Sea-anemones are among the most attractive of marine animals, beautiful both in form and color. They vary in size from that of a pin's head to several feet across, and they live at all depths and in a great variety of situations.

"A Coral Polyp is only a sea-anemone which deposits a plate of lime salts at the base of its barrel-like body and between the radial partitions of the stomach cavity. These lime salts form a stony skeleton or substance which we commonly call 'coral.' It is well to remember that the coral animals are not 'insects,' but are merely sea-anemones which form stony skeletons. Altho sea-anemones and Coral Polyps resemble beautiful flowers when fully expanded, they quickly contract into a mere dome-shaped mass when disturbed. In this way the coral polyps are protected by withdrawing into their stony cup-shaped bases.

"The Coral Polyps are glassy white and translucent, and have each from eighteen to twenty-four long tapering tentacles which end in a white knob and are speckled over with white warts. These are the stinging organs which enable the coral to capture its prey of small marine animals. When fully expanded the polyps are about one-eighth of an inch wide and three-eighths high, but when disturbed they suddenly contract so as to become practically invisible. The colony starts with a single polyp, but soon others bud out from its base, and the cluster increases by further budding from the bases of the older polyps until it may be several inches in diameter.

"The Fleshy Coral is found from the eastern end of Long Island to the Gulf of St. Lawrence. It is rarely seen in shallow water, but is common upon rocks at depths greater than twenty feet. When first brought up from the bottom it appears as an ugly, tough gelatinous mass covered with dull yellowish-pink finger-shaped processes. If placed in water, however, the whole mass soon appears studded with beautiful star-shaped polyps, which expand so as to give the appearance of a stump covered with delicate pink flowers. Each of these polyps has a terminal mouth surrounded by eight tentacles, the sides of which are bordered with rays giving a feathery appearance. The whole colony of polyps develops through constant budding from the sides and bases of the older parts of the colony.

"Nothing is more strangely beautiful than these coral reefs where the rich purple sea fans and the chocolate sea whips wave gracefully to the surges in the crystal depths, while brilliant fishes glistening in green, blue, purple and yellow glide in and out among the shadows of the coral caverns. The precious coral of the Mediterranean is allied to the Sea Whips. Its polyps are brilliant white, and have each eight feathered tentacles; while the internal axis of the colony is red and stony."

The Stony Corals, especially the reef-building kinds, have played an important part in the building up of the continents. They flourish in a warm temperature and clear water. In the West Indies, the Red Sea and Indian Ocean, the northeast coast of Australia, and especially in the islands of the Pacific coral reefs to-day are building out the land on a gigantic scale; and their influence has been even more important at times in the past history of the earth. The lower part of the peninsula of Florida consists of a succession of reefs built out one after another, the latest being the Florida Keys. The outer border of the reef is alive and growing, the fragments broken off by the waves from above filling up the interstices between the growing corals and slowly extending the bank seaward.

The lime extracted by the little coral polyps from the sea-water and built up into solid limestone reefs would in the course of time exhaust the entire supply of lime salts in the ocean, were it not continually recruited by the lime dissolved from limestones on land by the rain or liberated in the decay of other rocks. This lime is brought down by the rivers in the form of a soluble bicarbonate, and in extracting it from the sea-water the corals and other lime-secreting organisms set free a certain amount of carbonic acid gas, which again is not without effect upon the climate.

"Starfish, Sea-urchins, Sea-lilies and Sea Cucumbers, forming the order Echinodermata," says Mayer, "are also called 'radiates' because in the form of their bodies and arrangement of their organs they usually display five rays. For example, most starfishes have five equally developed arms, 72° apart, recalling the rays of a conventional star. In the Echinoderms the skin usually contains a skeleton composed of calcareous plates of definite shapes, all hinged together in an orderly manner, so as to make a veritable armor which gives rigidity to the body and protects the soft organs of the interior. In the living starfish one will see hundreds of little tubular feet which arise from the grooves on the lower side of the arms. When the starfish is turned over upon its back these feet stretch out to a remarkable length and wave about, seeking to fasten upon something in order to right the animal. It is then we may see that each of these feet is a hollow tube ending in a cup-shaped sucker.

"Similar tube-feet will be seen in five double lines along the sides of the sea urchins. The mouth of the starfish is at the center of the lower surface. On the upper side, and a little away from the center between two arms, one will see a spongy-looking area. This is called the madreporic plate, and is the sieve-like entrance to the water-tubes of the starfish, which extend down the arms and give rise to little bladder-like vessels one above each tube-foot. The contractions of these little bladders cause the tube-feet to elongate by pressing water out into their cavities. The upper surfaces of most of the starfishes are covered with spines, but these are much better developed in the sea urchins, where, in addition to spines, are found calcareous pincers mounted upon rods, which are used to remove any injurious foreign substance that may fall upon the body of the urchins.

"The sea cucumbers, or Holothuria, are worm-like in appearance, but are nevertheless closely related to starfishes and sea urchins. They have no spines and their skeleton is often reduced to minute anchor-shaped spicules within the skin. The mouth is at one end of the worm-shaped body, and is surrounded by feathered or branching tentacles. In some species there are five double rows of tube-feet down the sides of the body, but in others these are absent. When disturbed sea cucumbers have the curious habit of casting out their viscera and afterward regenerating them. They are sluggish creatures, and either live within the sand or under rocks or crawl slowly over the bottom, feeding upon minute organisms that are contained in the sand or mud which they swallow.

"Sea urchins, or Echini, may be compared to starfishes without arms. They are usually provided with a skeleton made for the most part of six-sided plates fused or rigidly joined together. They have five sharp-edged teeth with which they gnaw off minute seaweeds from the rocks. Some species can even gnaw away the rock itself, and in many parts of the world the sea urchins have literally honeycombed the rocks; indeed, a sea urchin is often found living in a cavity whose opening is too small to allow of the animal's escape. The common sea urchin of Europe is sold in the markets during the season when it is full of eggs.

"The Sea Lilies, or Crinoidea, may be compared to a starfish mounted upon a long stem which arises from the middle of its back and anchors it to the bottom of the sea. The mouth is turned upward, and is surrounded by branching arms which sweep gracefully to and fro in search of prey.

"The Echinoderms live only in salt water, but they are found at all depths and in all oceans, from the tropics to the poles. The vast majority crawl over the bottom, but at least one holothurian swims through the water, and was at first mistaken for a jelly-fish. Most of them cast their eggs out into the water, and the larvæ develop bands of waving cilia, which enable them to swim about for a considerable time. Suddenly the body of the Echinoderm begins to develop with the larva, and most of the old larval body is absorbed or cast off.

"Starfishes feed upon almost any kind of mollusk, but will also devour barnacles, worms, and occasionally sea urchins or even the young of their own species. It is estimated that in one year starfishes destroyed $631,500 worth of oysters on the beds of Connecticut alone. In the mode of feeding the starfish folds its arms over the clam or oyster, and hundreds of the sucker-like tube-feet fasten themselves to the valves of the shell, so that finally the mollusk yields to the constant pull of the starfish and the shell gapes open. Then the starfish turns its stomach inside out and engulfs the mollusk. It has been found by experiment that a large starfish can exert a steady pull of over two and one-half pounds, and that this is sufficient in time to open the valves of a clam or mussel.

"The eggs of the starfish are discharged into the water in greatest abundance during the last three weeks of June, altho they are also to be found throughout the summer, and occasionally even in winter. These eggs soon develop into little transparent larvæ covered with tortuous lines of waving cilia, and provided with long, flexible tubercles. They swim slowly about near the surface, and feed upon minute organisms until they grow to be about one-eighth of an inch long. Then the upper and lower halves of the star begin to develop upon both sides of the stomach, and in a few hours all of the anterior part of the larva and the tubercles are absorbed, and only a minute star about as large as a pin's head is seen upon the bottom of the ocean.

"Myriads of these little stars settle upon sea weeds and eel grass, and begin at once to devour the young clams which also begin life in the same places. Professor Mead found that one of these little stars devoured over 50 young clams in 6 days. The starfishes grow rapidly, and in one year they may have arms 2½ inches long and be ready to spawn."

Besides the common five-pointed starfish there are many others more or less familiar. The Serpent-stars have long, slender, flexible arms and are much more active; in the Basket-stars the arms are branched and forked into a multitude of slender interlaced tips upon which the animal moves about with the body lifted above the ground.

The prickly sea urchins abound along rocky coasts; along the sandy shores they are replaced by the sand-dollar, flattened out into a thin plate covered with minute brown spines. Sea cucumbers are familiar to every one who has explored the tide-pools of rocky coasts at low water, but other kinds are common on sandy, muddy or gravelly beaches, living just below low-water mark. In China a species of sea cucumber is prepared and eaten as a delicacy. Sea lilies, or Crinoids, are now rare and confined to deep water, but in the early periods of geologic time they were very abundant and varied, shore forms as well as deep-water species. The oldest of them, dating back to the Cambrian Period, suggest a sea urchin which has lost its spines and is mounted upon a jointed stalk; in the Crinoids proper the body has developed branching arms which wave in a feathery plume above it. The fossil crinoids, or "stone-lilies," are sometimes preserved in wonderful perfection in the Paleozoic limestones, and are one of the most attractive of fossils. Great numbers of them have been obtained in the limestones of Crawfordsville, Indiana, and elsewhere in the United States.

"The title 'Worms,'" says Professor Thomson, "is hardly justifiable except as a convenient name for a shape. The animals to which the name is applied form a heterogeneous mob, including about a dozen classes whose relationships are imperfectly known. But the zoological interest of the diverse types of worms is great. For amid the diversity we discern affinities with Cœlenterata, Echinoderms, Arthropods, Mollusks and Vertebrates.

"Moreover, it is likely that certain worms were the first to abandon the more primitive radial symmetry, to begin moving with one part of the body always in front, to acquire head and sides. And if one end of the body constantly experienced the first impressions of external objects, it seems plausible that sensitive and nervous cells would be most developed in that much-stimulated, over-educated head region. But a brain arises from the insinking of ectodermic (skin) cells, and its beginning in the cerebral ganglion of the simplest 'worms' is thus in part explained."

Most of the creatures which fall into this group are of little interest to the general reader. Many of them are parasitic; some, like the Tape-worms, Thread-worms, Flukes and Trichinæ, are unpleasantly familiar in this connection. The simpler Unsegmented Worms are those which most nearly represent the remote ancestors of mollusks and of vertebrates; the higher Segmented Worms, or "Annelids," follow more definitely along the line of crustacean and insect evolution. In them may be found an arrangement of organs and plan of bodily construction which serves to explain how the organization of the crustaceans and insects has been developed.

The Common Earthworm is the most familiar of the annelids, and its anatomy is much more interesting and complicated than might at first be supposed. The surprise is great that awaits the man who first dissects an Earthworm. With proper cleaning and dissection he will be able to see a complex and wonderful structure, a plan of organization wholly different from that of the higher animals (vertebrates), yet subserving to a large extent the same purposes, and beautifully adapted to the needs of the Earthworm's life and habitation. To tear up that delicate mechanism on the prongs of a fishhook is likely afterward to appear to him a sort of disregard of proportions, much like throwing a gold watch at a stray cat.

Of the anatomy a detailed account cannot be given here. It must suffice to say that it has a straight alimentary canal stretching from the mouth at the front end to near the hinder end of the body, the front end of the canal being provided with a muscular ring and with glands which aid it in swallowing and digesting the earth which forms its food. There is a circulatory system, consisting of a slender tube along the mid line of the back and others along the under side, joined by several cross veins encircling the throat, which by expanding and contracting enable the colorless blood to circulate through the body. It possesses also a nervous system consisting of a cord corresponding to the spinal cord of higher animals, but situated on the under side of the body along the middle line, and double instead of single, with little knot-like expansions or ganglia at every segment, which correspond to the brain of the higher animals, and with a separate pair of ganglia on the dorsal (upper) side of the head united with the front pair of ganglia of the under side by a pair of cords encircling the gullet. There are no eyes or other specialized sense organs, no special organs of respiration; yet the worm is aware of the approach of enemies or of light and darkness through a general sensitiveness of the skin, and the blood is aerated through the skin. There are, however, the beginnings of organs of excretion, to remove waste matter from the circulation, and the reproductive system is quite elaborate, the animal being hermaphrodite—that is, combining both sexes in one individual, but so arranged that the eggs of one Earthworm must be fertilized by another.

The chief economic importance of Earthworms is as principal agents in forming the mantle of humus, or soil, which covers the dry land in all parts of the world, and buries the hard rocks and sterile soil beneath it. Earthworms abound in all parts of the world; they eat their way through the soil and come out at night to the surface, where they forage around for leaves and stray bits of vegetable matter, which they drag to their burrows to be nibbled and swallowed at leisure. Their castings, composed of the earth and comminuted vegetable matter which they have swallowed and digested, are deposited on the surface, and in the course of their lives they bring up a good deal of the sterile under soil, mix it thoroly with particles of vegetation from the surface, and deposit it in their castings. These, accumulating year after year and century after century, form the layer of humus, or top-soil, in which vegetation chiefly thrives and on which the gardener and farmer depend for the successful growth of their crops.

Not all the humus is due to Earthworms—insect larvæ play some part, and to a large extent it is merely due to natural decay of surface vegetation and its mixture with soil by rain and the dust brought by the winds. But the investigations of Darwin showed that the Earthworm plays an important part in its formation. Thus as the tiny Coral Polyp is ever helping to form the continents on which man can live, and perhaps also to control the climate and moderate the extremes of temperature, so also the Earthworm is rendering efficient aid in covering the land with rich and fertile soil, enabling vegetation to flourish and making the earth habitable for the human species.

The name "mollusks," or soft-bodied animals, covers an immense number and variety of invertebrates, the Clams, Oysters and other shellfish, the Snails and Slugs, the Octopus and Squid, and many less familiar types. All of them have soft bodies, usually with an external calcareous shell, but with no internal skeleton except in the Squids and their relatives. They are much more highly organized than the Coral or Starfish groups. The arrangement of the organs shows a bilateral symmetry, unlike the radial symmetry of Coral or Starfish. That is to say, the organs and parts of the body are arranged in pairs on each side of the middle line, so that there is a front and a hinder end to the body. On the other hand, the body is not divided into successive segments as in the worms, crustaceans and insects. Most of the mollusks are sluggish animals, many of them attached to stones or other objects on the bottom, but the Squid and Cuttlefish are swift and active.

"The lower surface of the body," says Mayer, "consists of a thick muscular 'foot' used in creeping. In front of the foot is the head, which may have a pair of eyes and tentacles; while the mouth lies on its lower surface and is often provided with numerous horny, rasping teeth. A flap-like fold of the body extends outward from the sides. This fold is called the 'mantle,' and its free edge and upper part secretes the shell which usually covers the back of the mollusk. The feathery gills arise from the sides and lie in the space between the lower side of the mantle and the side of the body. The intestine is coiled and opens typically at the posterior end of the body, behind the foot. There is a paired digestive gland or 'liver' which pours its secretion into the mid-gut. The three-chambered heart lies above the hind gut and pumps blood from the gills to other parts of the body." In addition, it may be noted that the mollusks show well-defined muscles and nervous system.

The latter consists of a number of ganglia, knots or nodes of "gray matter," corresponding in function more or less to the brain of higher animals, connected by cords of nerve fibers which may be said to correspond roughly to the spinal cord in higher animals. From these ganglia nerves are given off to the various parts of the body. This concentration of the nervous system into a few defined ganglia connected by cords is a great advance upon the condition in the lower invertebrates, where the nerve cells are diffused and scattered over the surface of the body. It makes possible a much more exact and definite correlation of the movements and actions of different parts of the body. It is like the establishment of a central executive bureau to control and order the activities of some great and complex organization.

The great majority of mollusks are marine, chiefly shore-living, altho some are adapted to a deep-sea life. But many inhabit fresh-water lakes, rivers and streams, and one group, the Land-snails, has become adapted for terrestrial life, breathing air instead of water.

The principal groups of mollusks are: (1) The Bivalves, or Lamellibranchs, comprising clams, oysters, mussels and other shell-fish in which the shell consists of two valves, right and left; (2) Snail-shells, or Gasteropods, including snails, whelks, periwinkles, limpets and others in which there is a single valve, mostly spirally coiled; the symmetry of the animal is obscured in this group by development of one side; in the Slugs the shell has degenerated to a small, horny scale buried in the body; (3) Squids and Cuttlefish, or Cephalopods, including also the octopus, nautilus and a host of extinct forms; they are free-swimming, active animals with a ring of muscular tentacles around the mouth and part of the "foot" modified into a funnel, the "siphon," through which water can be forcibly expelled from the mantle cavity, driving the animal backward; these are considered the highest development of molluskan life, on account of their active habits and more concentrated nervous system.

The Lamellibranchs feed upon minute organisms, both animal and vegetable, which they sift out from the sea water by the aid of gills. The gasteropods are more generally carnivorous, feeding upon other mollusks, which they attack by boring a hole in the shell by means of a ribbon-like tongue, the "radula," armed with many small, sharp, horny, rasping teeth, and then sucking out the juices of their victims. This unique little implement appears to be very efficient for its purpose, and is said to be aided by a secretion of sulphuric acid. Other gasteropods, such as the periwinkles and the fresh-water and land snails, feed upon plants, but all of them possess the radula. The cephalopods also are carnivorous, the Octopus lying in wait for unwary fish or crustaceans which may come within reach of the long tentacles, the Squids capturing their prey by darting rapidly backward, swinging quickly to one side and seizing the victim in their sucker-bearing arms.

The mollusca include an immense number and diversity of animals. In the Gasteropoda alone there are over fifteen thousand living species; the Lamellibranchs are hardly less numerous. Many of them are edible, a few are important articles of food. The oyster fisheries in the United States alone are estimated to yield $16,600,000 annually. The soft-shell clam of the North Atlantic, the scallop and the round clam or quahaug of the Middle Atlantic States, are important articles of commerce, while mussels, whelks, periwinkles and land snails also are largely eaten in Europe. The pearl oysters of the Indian and Pacific oceans and the fresh-water pearl-clams of the United States are likewise of importance, not only for the pearls, but for the much larger industry in mother-of-pearl obtained from the shells and manufactured into buttons and pearl ornaments. The pearl fisheries in the Persian Gulf alone are said to be worth $2,000,000 annually.

The noxious activities of mollusks are slight. A few species commit depredations upon oyster-beds; the damage done by the teredos to timber under water is more serious. The gruesome tales of attacks upon man by the devil-fish or octopus are mostly fanciful. An octopus, if large enough, no doubt could and would attack a man if he came within reach. And once in a while he might catch him at a sufficient disadvantage to overcome and destroy him. But the chances for such an encounter with such a result are exceedingly small. Members of this group of mollusks do attain a gigantic size, however. These huge forms are deep-water organisms, and are very rarely seen by man, altho they form an important part of the food of marine mammals such as the seals and sperm-whales.

During the whole of recorded geologic time mollusca have been an important element in the marine fauna; fresh-water mollusks are probably equally ancient, and land mollusks are known to have appeared as far back as the Coal Era. Their hard, indestructible shells are the most abundant of fossils, often making up the entire mass of limestone strata. Lamellibranchs, gasteropods and cephalopods were all distinct as early as the Cambrian Period; their evolution from a common stock must date far back into the unrecorded beginnings of geologic time. The shelled cephalopods, related to the modern nautilus, attained great size and abundance early in geologic time, and were then the dominant type of marine life. In Orthoceras the shell is sometimes seven feet long, straight instead of coiled as in the nautilus. During the Age of Reptiles the cephalopods were again very abundant marine forms, the Ammonites, Baculites, etc., coiled, partly coiled or uncoiled, being probably more nearly related to the squid and octopus than to the nautilus.

But the majority of fossil shells are related to the modern lamp-shells and their allies, the Brachiopoda, which, altho mollusk-like, are not true mollusks, the plan of organization of the animal being wholly different. The shell may be distinguished by the fact that its valves are dorsal and ventral, instead of right and left, with respect to the symmetry of the animal. These Brachiopoda are considered a class apart, or grouped with Bryozoans into the "Molluscoidea." Their relations are about as close with worms as with mollusks, but not very near to either. The living brachiopods are rare deep-water organisms, crowded out from shallow water by competition of the more highly organized mollusks; but in early geologic times they were the common shells of the sea-shore.

With the Crustaceans begins the Arthropod series of invertebrates, characterized by a segmented body, jointed limbs and an outside skeleton. The name (arthro-poda, jointed feet) points to the distinction that separates them from the worms; but their plan of organization is evidently derived from that of the segmented worms or Annelids. The crustaceans are adapted to aquatic life and breathe by gills; the insects are adapted to terrestrial life and breathe by tracheæ; the spiders and their allies include both land and aquatic types, differing from either insect or crustacean in their plan of organization.

The lobster and crayfish are the most typical crustaceans, the first marine, the second living in fresh water. In comparison with the worm, it is observable that while the body is segmented, the segments are not all alike, but are divided into two regions, the head-and-thorax and the abdomen. Likewise the appendages are not mere bristles as in the worms, but jointed, and specialized to serve different purposes. The most anterior ones, antennæ and antennules, are organs of touch and smell, enabling the lobster to feel his way about; next come six pairs which serve chiefly to aid in biting and chewing the food; then the large forceps to seize the prey; then four pair which are used in walking; and six posterior pairs used mainly for swimming purposes. Altogether there are nineteen pairs of appendages. The stalked eyes are not classed as appendages, being of different origin. The segments and appendages are enveloped in a tough, horny covering, flexible at the joints, hardened elsewhere by lime salts into a rigid armor.

The internal organs of the lobster are much more elaborate than in the worm, but their general plan is much the same. The nervous system is more concentrated; the muscles are distinct and well developed; the alimentary system consists of, first, a gizzard with a complex mill for grinding up the food, then a mid-gut stomach with a large digestive gland which takes the place of liver, pancreas, and in part the stomach glands of higher animals; and finally a long straight hind-gut, which takes but small part in the digestive process. The colorless blood enters the heart from the gills through valves which admit of entrance but not of exit. Thence it is pumped through well-defined arteries to the tissues of the body, from which it returns through ill-defined channels to the gills. The gills are feathery structures of a rather complex nature, presenting a large surface to the current of water which the animal keeps going through them by paddling with part of the fifth pair of appendages. There is also a distinct excretory system (kidney), and the reproductive organs are more elaborated than in the worm, the sexes being separate. It is thus a much higher type of animal than the earthworm, but the plan of organization is the same, as it is also in the insect. The mollusk and the vertebrate are organized upon entirely different plans.

The lobster occasionally attains great size, and one specimen, three feet and six inches long and 30 pounds in weight, was captured off the New Jersey coast in March, 1897.

The Snapping Prawns are little lobster-like crustaceans of the American coast. The largest are not more than one and three-quarters inches long. One claw is much larger than the other, and is provided with a sharp-edged blade which is normally held out at right angles to the claw. At the least alarm this blade is closed with a sharp snap, reminding one of the explosion of a small torpedo. These little creatures live in crevices of coral reefs, under shells and stones and fairly swarm in sponges; so that when a sponge is lifted from the water it crackles as if filled with minute firecrackers. The Shrimps are similar in many ways, but are free swimmers.

A Crab is essentially a lobster with its tail turned in under its body. It is the highest of the Crustacea, and the species is widely distributed and varied, extending from the combative edible or blue crab to the parasitic hermit crab; ranging in size from the tiny oyster crabs which live within the gill cavity of the oyster to the giant spider crab of Japan, which attains a span of twelve feet; including deep sea crabs which never come to the surface and the land crabs of the tropics which rarely enter the water, and which, like the robber crabs, climb trees and live on cocoanuts.

Barnacles, while mollusk-like in appearance, are really crustaceans which have affixed themselves to rocks or floating objects and are enclosed in a hinged calcareous shell. As Huxley put it, "They are fast to a rock by their heads and kick the food into their mouths." The stalked barnacle, or "goose-barnacle," was believed by writers of the Middle Ages to undergo a metamorphosis into a species of goose—the "barnacle-goose"—and this transformation was repeatedly asserted in the most positive terms down to the time of Linnæus or even later.

"Being encased in a natural armor," says Mayer in "Seashore Life," "crustaceans cannot grow at a uniform rate, but enlarge suddenly at the periods when the shell is shed. This occurs at fairly regular intervals, and the entire shell is shed, even the coverings of the eyes and part of the lining of the stomach being cast off. The creature is then soft and helpless, and usually remains hidden in some safe retreat until the body has expanded and the new shell hardened."

Owing to their hard outer armor and their aquatic life, remains of crustaceans are very common as fossils, and there is a fairly complete record of their evolution. The higher types, such as crabs and lobsters, did not appear until after the Coal Period. But the more primitive, mostly minute crustaceans known as Ostracods and Phyllopods have been traced as far back as the Cambrian, nearly to the beginning of recorded geological history.

The Trilobites, familiar to every geologist, were a primitive group of crustaceans which flourished during the older geologic periods, becoming extinct in the Coal Period. They are very abundant and characteristic fossils in Paleozoic strata. Many of them attained considerable size, the largest up to two feet in length.

CHAPTER IV

THE HIGHER INVERTEBRATES

It seems natural to think of a spider or scorpion as an insect. But in fact they are not true insects, altho they belong to the Arthropod series of invertebrates. All insects have three pairs of legs and breathe by tracheæ. Spiders and scorpions have four pairs of legs and breathe by "lung-books," an apparatus like modified gills. And in all the details of their anatomy spiders and scorpions are as different from insects as they are from crustaceans. All insects (excepting, perhaps, a few unimportant primitive kinds) have wings or have had them at a former period in the development of the race; altho in many groups the wings are degenerate or lost. Scorpions and spiders appear never to have developed wings at all.

In short, the insect class may be regarded as an adaptation of the Arthropod invertebrates to aerial life; the spider class to terrestrial life; the crustaceans to marine life. Each, in its own element, has had a long and more or less successful career; each has made attempts to invade the territory of the others. For in the West Indies and other oceanic islands are crabs which pass their life mostly on dry land; and the spider swinging in air from a slender thread, and even in some cases traveling through the air on a long film of unattached gossamer, is emulating the habits of the flying insect. But the insects alone have invaded the alien habitats with any great success, and so far as terrestrial life is concerned they have crowded the spiders and scorpions to the wall.

Scorpions are found only in tropical countries, and are distinguished by the elongate tail with venomous tip and the large-clawed grasping legs in front. They have four pairs of walking legs like spiders. In the old natural history books they are credited with committing suicide when unable to escape by stinging themselves to death. Unfortunately for the story, aside from the argument that the mental processes of the lower animals are not very likely to lead them to deliberate suicide, the feat is anatomically impossible, and if it were possible the poison would have no effect.

Spiders are common everywhere, and, like scorpions, they are all carnivorous, sucking the juices of insects which they capture. Many of them, but not all, form webs, and the construction of the web is a remarkable piece of engineering, which must involve highly elaborate instincts comparable only to those of the higher insects.

The material of the web is a liquid silk secreted by the spinning glands and forced through the fine tubes of the "spinnerets," hardening immediately on exposure to the air. The spun threads are used also to line the nest, to envelop the cocoon, and to assist the spider in his aerial gymnastics.

The Spiders are by no means confined to webs, but certain of them construct more permanent dwellings. Thus the Mason Spiders dig a hole in the ground, and then spin across and across the mouth of it a woven door with a hinge at one side. Even less known and more curious is the work of a little water-spider, who, not desiring to forego the power of air breathing, spins a silken diving bell, wherein is imprisoned a globule of air.

Male spiders are very much smaller than the females, the difference in bulk being sometimes as 1,300 to 1, and more brightly colored.

With spiders and scorpions are classed various parasitic insects, such as mites and ticks, and other minute and degenerate forms. The King Crab or Horseshoe Crab has also been discovered to be more nearly related to the Arachnoids than to the Crustaceans, which it resembles in appearance and habitat. And another group of aquatic animals, the Eurypterids, now extinct, is regarded as most nearly related to the scorpions among living animals. The Eurypterids inhabited brackish or fresh water during the Paleozoic era, and some of them attained a length of six or seven feet, a truly formidable size for that ancient period.

The numbers and variety of insect life are far beyond those of any other animals, at least upon the land. More than half the described species of zoology are insects—more than three-fourths of the land animals belong to this class. And the innumerable hosts of some sorts make them, despite their small size, the most dreaded and dangerous enemies with which man has to contend. The seriously noxious insects are indeed a small minority—most are indifferent so far as man's welfare is concerned—a few are actively beneficial. But as a class, it must be affirmed that the harmful activities of insects outweigh their beneficial action. They are rivals with man for the possession of the fruits of the earth, and if to the damage on this score be added their activities as carriers of infectious diseases, they may well be regarded as the most formidable enemies of man in the animal kingdom.

The insect is an evolution from the primitive worm or annelid type, adapted to terrestrial life as the crustacean is to marine life, and the structure and plan of organization is much the same in both. There are two most important differences. The first of these is that the crustacean breathes by gills, the insect by tracheæ, branching tubes which ramify into every part of the body, and by expanding and contracting take in fresh and expel vitiated air, as do our lungs. The second difference is that the insect has wings, generally four of them. The arrangement of the nervous system, the circulation, the appendages and mouth parts, the sense organs and the alimentary system are much as in crustaceans.

In comparison with higher vertebrates of the land, the insect shows a fundamentally different plan of organization. Thus, in a vertebrate the principal nervous system is along the dorsal, in an insect along the ventral side of the animal. In a vertebrate the jaws open up and down, and the teeth are originally modified scales; in an insect the jaws open sideways and the teeth are modified legs. In a vertebrate the skeleton is internal, in an insect it is external. The heart of a vertebrate is in its thorax, the stomach in its abdomen; in an insect the position is reversed. The vertebrate pumps vitiated blood from the tissues to the lungs to be aerated; the insect pumps fresh air to freshen the vitiated tissues directly. The wings of a bird or a bat are modified legs; the wings of an insect are outgrowths from the skin of the back. And so on throughout. The resemblances between insects and land vertebrates are mostly superficial; their plan of organization is wholly different, and the similarity is due to both being adapted to live on land. The resemblances between insects and crustaceans indicate relationship; their plan of organization is fundamentally the same, the differences being due to adaptation to terrestrial life in the one, to aquatic life in the other.

Note that there are water insects and likewise land crustaceans. But the land crustaceans still breathe by gills, a method evidently adapted for water-breathing. And the water insects are dependent upon air for breathing, so that they have to come to the surface from time to time at least.

The most important feature of the development of the higher orders of insects is the metamorphosis or change of form from larval to adult. The egg hatches into a larva wholly different from the adult in form, internal organs, and manner of life, and the larva in changing to the adult form undergoes a metamorphosis which involves the almost complete breaking down of all the structures of the body into a mass of formless tissue, and the rebuilding out of this formless tissue the organs and parts proper to the adult.

This extraordinary change takes place in from two or three days to several weeks, and the insect undergoing it is called a pupa. In the lower orders of insects there is no metamorphosis or a very incomplete one. The meaning of this change and the object of it in furthering the interests of the insect is not very clear. Obviously the wingless crawling larva may be regarded as having once represented the ancestral type from which the insect is descended, but as now greatly altered to fit the requirements of its own (juvenile) habits and environment. And it is possible to explain the breaking down of the old tissues into a formless mass of cells by supposing that larva and adult have each proceeded so far on their divergent specializations of structure and form in adaptation to the needs of each, that it has become cheaper, so to speak, to break down the old tissues and build anew, rather than to modify the old into the new tissues along the lines of natural development.

Setting aside certain primitive wingless insects, the three orders Ephemerida, Plecoptera and Odonata (Mayflies, Stone-flies and Dragon-flies) are given lowest rank among insects because of their incomplete metamorphosis. All of them haunt the fresh-water ponds, rivers or streams wherein their larvæ dwell, and are not seen far away from water. The larvæ are at first wingless, provided with gills instead of spiracles, so that they are not obliged to come to the surface. They develop rudimentary wings during their larval life, and change to the adult form by a succession of molts like crustaceans, without any breaking up of the internal structures.

The dragon-flies "are unexcelled among insects," says Kellogg, "for swiftness, straightness and quick angular changes in direction of flight. The successful maintenance of their predatory life depends upon this finely developed flight function, together with certain structural and functional body conditions which might be said to be accessory or auxiliary to it. All have four well-developed wings. The body is long, smooth and subcylindrical or gently tapering. This clean, slender body offers little resistance to the air in flight and serves as an effective steering oar. The wings are long and comparatively narrow, fore and hind wings being much alike. . . . The head is unusually large, and more than two-thirds composed of the pair of great compound eyes. More than 30,000 facets have been counted in the cornea of certain dragon-fly species. For accurate flight and successful pursuits of flying prey, the dragon-fly has full need of good eyes. The jaws are strong and toothed, and obviously well adapted for tearing and crushing the captured prey.

"When the prey is come up with, however, it is caught, not by the mouth but by the 'leg-basket,' and then held in the fore legs while being bitten and devoured. The internal anatomy is specially characterized, as might well be imagined, by a finely developed system of thoracic muscles for the rapid and powerful motion of the wings and the delicate and accurate movements of the legs. The respiratory system is also unusually well developed.

"The prey of the dragon-fly may be almost any flying insect smaller than itself, altho midges, mosquitoes and larger flies constitute the majority of the victims. The good that is done by dragon-flies through their insatiable appetite for mosquitoes is very great. Now that we recognize in mosquitoes not only irritating tormentors and destroyers of our peace of mind, but alarmingly dangerous disseminators of serious diseases (malaria, yellow fever, filariasis), any enemy of them must be called a friend of ours."

Dragon-flies are a very ancient race of insects. They tenanted the strange antique forests of the Coal Period, and some were, for an insect, of gigantic size, one having a spread of wing of nearly two feet. Others are found in the still older forests of the Devonian. And indeed it is to the ancient life and ancient land that dragon-flies seem peculiarly appropriate. The dark, somber tropical swamp-forests of those early days, their trees gigantic club-mosses, ferns and horse-tail rushes, before the appearance of flowers, of broad-leaved trees, of land vertebrates, seem peculiarly fit to be tenanted by insects which to-day are associated with similar life-conditions and which have no relations with flowering plants or with the higher developments of insect life.

The various kinds of bugs, scale-insects and plant-lice which make up the order of the "Hemiptera," or Bugs, have the mouth parts modified into a sucking beak. They feed upon the juices of living plants or the blood of living animals, and include the worst of insect scourges. Owing to their sucking habits, they are more difficult to combat than the biting insects, and their fecundity is enormous.

"The order of Hemiptera," says Kellogg, "includes over 5,000 known species of North American insects, representing a large variety and a great economic importance. Some of the most destructive crop pests and most discomforting insect scourges of man and the domestic animals belong to this order. The chinch-bug's ravages in the corn and wheat fields of the Mississippi Valley offer effective evidence to the dismayed farmers of the workings of a displeased Providence; the tiny sap-sucking aphids and phylloxera and insignificant-looking scale-insects make the orchardist and vine-grower similar believers in supernatural moral correction by means of insect scourges; and the piercing and sucking lice and 'bugs'—in the English meaning—make personal and domestic cleanliness a virtue that brings its own immediate reward. . . . The name Hemiptera is derived from the character of the forewings shown by most, tho by no means all of the members of the order; this is the thickening of the basal half of the otherwise thin membranous wing, so that each fore-wing is made up of two about equal parts of obviously different texture and appearance; hence 'half-winged.' All Hemiptera (except the male scale-insects) have an incomplete metamorphosis, the young at birth resembling the parents in most essential characteristics except size and the presence of wings. By steady growth, with repeated moltings and the gradual development of external wing pads, the adult form is reached, without any of the marked changes apparent in the insects of complete metamorphosis. With similar mouth parts the young have, in most cases, similar feeding habits, preying upon the same kinds of plants or animals that give nourishment to the parents.

"The extent of the injuries done by various members of this order to farm and orchard crops, to meadows and forests, and to our domestic animals is enormous. Of the other insects the order of beetles includes numerous crop pests, and the caterpillars of many moths and a few butterflies do much damage; locusts have a healthy appetite for green things, and many kinds of flies could be lost to the world to our advantage, but perhaps no other order of insects has so large a proportion of its members in the category of insect pests. The single Hemipterous species Blissus leucopterus, better known by its vernacular name of chinch-bug, causes an annual loss to grain of twenty millions of dollars; the grape phylloxera destroyed the vines on 3,000,000 acres of France's choicest vineyards; the San José scale has in the last ten years spread from California to every other State and Territory in the United States and become a menace to the whole fruit-growing industry. So despite their small size and their general unfamiliarity to laymen, the Hemiptera are found by economic entomologists, in their warfare against the insect scourges of the country, to be one of the most formidable of all the insect orders."

Remedies for sucking insects are not readily found. Kerosene emulsion is the one chiefly employed. Fumigation or spraying with tobacco is effective on a small scale, and for scale insects when the leaves are off the trees, hydrocyanic acid fumigation or lime-sulphur-salt spraying are used. The orange-scale has been successfully held in check by importing and fostering a lady-bird beetle which feeds upon it; and the chinch-bug by introducing a parasitic fungus which kills the bugs by wholesale when the weather conditions favor its spread.

The order "Orthoptera" includes the cockroaches, locusts, grasshoppers and crickets, all familiar types of insects, many of them of large size, and several ranking among the important noxious insects. On the other hand, their active leaping and noisy flights, their cheerful trilling and chirping lend a variety and interest to outdoor life which one might sadly miss if deprived of their companionship. Their music is rather instrumental than vocal, since it is made by rasping the wings against each other or against the roughened inner surface of the thighs.

In all this order the mouth parts are modified for biting, and they mostly live on vegetable food, especially upon green leaves. In the grasshoppers, locusts and crickets the hind limbs are modified for leaping; the cockroaches, praying insects and walking-sticks are walking or running types. The roaches are one of the most ancient and persistent groups of insects. They shared with the dragon-flies the dominance of the ancient forests of the Coal Period, and are to-day a familiar household pest, especially in tropical countries and aboard ships. The mantis or praying-insect is a carnivorous type, feeding upon flies or other insects which may come within reach, and its curious attitudes have caused a variety of fanciful or superstitious legends to gather around it. To kill a mantis is very generally considered sinful or unlucky, and among the quaint monkish legends is one of St. Francis Xavier, who, "seeing a mantis moving along in its solemn way, holding up its two fore legs as in the act of devotion, desired it to sing the praise of God, whereupon the insect caroled forth a fine canticle."

The most singular of the Orthopterous insects are the walking-sticks, which mimic the green twigs and stalks of grass among which they live, in form, color and characteristic attitudes, so closely that they are one of the best examples of "protective mimicry."

The swarms of locusts which from time to time descend upon cultivated agricultural regions, devouring every green thing in their path, and bringing ruin and desolation to the farmer, are now known to be normally inhabitants of the high-lying grassy plains, driven from their accustomed feeding grounds by exceptionally dry seasons which have withered and destroyed the grass of the high plains. They cannot maintain themselves permanently in the moist climate of the low-lying valleys; and for their periodical incursions there is little remedy except to fight them in the high dry plains which are their natural home.

The Termites, or White Ants, are quite unrelated to the true ants, and quite unlike them in appearance. They belong to the lower orders of insects; the young are like the adult from the time they emerge from the egg, and do not undergo any metamorphosis. But, like the ants, they have an elaborate social organization and live in great colonies, mainly composed of sterile workers of several castes. Among the ants, bees and wasps these sterile workers are always females; with the termites they are of both sexes. The colony is presided over by a "royal pair" whose functions are confined to egg-laying. As with the ants, the workers are wingless, and the fertile males and females are winged only during the swarming season, when they leave the nest to found new colonies.

Termites live upon dead wood and are abundant mainly in tropical or sub-tropical regions, where they are fearfully destructive to all wooden buildings, furniture, etc., except they be constructed from some of the few kinds of wood that are immune to their attacks. The great hillock nests which they construct are a prominent feature of the landscape in some parts of tropical Africa. Their habits and complex social organization are almost as remarkable as those of the ants, but the communal instinct is not quite so strongly developed.

With the Beetles, or "Coleoptera," begins the series of higher insects with complete metamorphosis. That is to say, the young develop from the egg into a larva, quite unlike the adult in form, structure and habits, wingless and more or less worm-like in appearance and habits. After a period of active growth the larva becomes quiescent, wrapping itself up usually in a cocoon or protective case, and undergoes a remarkable change, the organs and tissues of the body being largely broken down and reformed, and finally the completed insect, or imago, issues from the cocoon or cell, perfect in form and widely different from the larva not merely in its external form, but in the whole internal structure as well. This extraordinary change, which has often been used as an apt natural illustration of ethical regeneration, is one of the most striking and wonderful features of insect life. It is completely carried out in the beetles, moths and butterflies, the lace-winged flies, the two-winged flies, and in the ants, bees and wasps. The lower orders of insects exhibit various degrees of approximation toward it, but in none of them is it complete.

The beetles include a vast multitude of different species and genera—12,000 species are known from the United States and Canada alone. All of them are distinguished by the hard, horny fore-wings which serve as a sheath for the membranous hind-wings, these alone being used for flight. The body is compact in form, covered by hard, horny skin, and the mouth parts are adapted for biting, the jaws often strong and large. Some beetles are predaceous, others, and these the great majority, are plant eaters, and some of them are notorious pests. Among the noxious beetles may be especially noted the "potato-bug," wire-worms, white grubs and other beetle larvæ, fruit and grain weevils, apple-tree borers, and a host of less important ones. The predaceous beetles, on the other hand, are actively beneficial by destroying quantities of noxious insects.

Among the handsomest members of the order are the tiger-beetles and the various predaceous ground-beetles, active, alert, many of them of bright metallic color patterns. Many beetles, like the fireflies and glow-worms, are luminous at night; some of the tropical fireflies emit light enough to read by when a few of them are placed under a glass. The stag-beetles and rhinoceros-beetles are among the largest of a group (Lamellicornia) notable for the huge mandibles and various peculiar horn-like processes developed in the males of many of the species. The numerous kinds of wood-boring species, some of them of giant size, do serious damage to orchards and forests. The little round ladybird beetles or ladybugs, with their "polka-dot" pattern of red and black, on the other hand, are a great help to the gardener and the fruit-raiser, as they feed upon plant-lice and scale-insects. In the large group which includes the curculios, weevils and snout-beetles, the front of the head is prolonged into a long beak, at the tip of which are the small, sharp jaws; many of these also are serious insect pests.

The "Diptera," or Two-winged Flies, includes gnats, mosquitoes and the innumerable kinds of true flies, an immense group, including some fifty thousand species, many of them familiar from the annoyance they inflict on men and animals, and in recent years more seriously considered as carriers of disease. The mouth parts in all are adapted for sucking and piercing, and they have but two wings, the hinder pair being converted to little structures which are used to balance or direct the fly in his flight.

The mosquitoes are familiar from the tropics to the poles, but it is only in recent years that their relations to three serious diseases of man have been suspected and proved. It has been shown beyond question that the germs of malaria, yellow fever and filariasis are transmitted from man to man through the agency of mosquitoes. The life history of the malaria germ has been quite thoroly investigated. Malarial fever, which is the most deadly disease of the tropics, is caused by a minute amœba-like one-celled organism, parasitic in the blood-corpuscles. These grow and multiply asexually in the human blood, but their sexual multiplication occurs within the stomach-cavity of the mosquito "Anopheles." Thence they make their way to the poison-gland of the insect, and are so introduced into the body of the next person bitten by this species. The "Anopheles" is the mosquito with spotted wings, fortunately less common than the gray-winged or brindle-winged mosquitoes of the genus "Culex." Another mosquito, "Stegomyia," is responsible for the dissemination of yellow fever and of filariasis, the life history of the germ proceeding along much the same lines as with the malaria germ, so far as it has been investigated. The destruction of mosquitoes, especially of the "Anopheles" and "Stegomyia," and protection from their attacks, have consequently been recognized as a most important safeguard to health, especially in tropical countries. Protection is chiefly to be had by extensive and thoro screening of houses and porches; destruction of the mosquito larvæ can be effectively accomplished by draining swamps and stagnant pools in which they chiefly breed, and where draining is impossible by periodically covering the surface of the water with a thin film of kerosene. Standing water in cisterns or rain-barrels should be carefully screened. By these methods of prevention the mortality from malarial fever and yellow fever in tropical regions has been greatly reduced when, as in the construction of the Panama Canal, they have been sytematically and thoroly applied. The smaller gnats and midges are nearly related to the mosquitoes, and are equally a pest throughout the world from their bloodthirsty habits.

The compact heavy-bodied flies, with short antennæ, are a much larger group than the mosquitoes, and many of them attain large size. The great majority are harmless to man, a few beneficial as they prey upon noxious insects; but some do serious injury to growing crops, the larvæ or maggots feeding upon the leaves or roots of the plants; a few, such as the bot-flies, are parasitic upon animals or man; and others, like the house-flies, blow-flies and their allies, are annoying and disgusting pests and dangerous spreaders of disease. The agency of the house-fly in disseminating typhoid fever in cities and camps has been properly appreciated only in recent years. Doctor L. O. Howard has recently suggested that in view of its activities in this direction it might most appropriately be called the "typhoid fly." This fly breeds in stable-manure and other decaying matter, and thoro clealiness and sanitation has already accomplished wonderful results in reducing the death-rate from diseases which are largely spread through its agency.

Related to the flies, altho given a separate ordinal rank, are the fleas, degenerate blood-sucking parasites of mammals and birds which likewise take part in the dissemination of certain diseases. They are wingless, with peculiarly compressed bodies and mouth parts adapted for piercing and sucking.

"The Moths and Butterflies (order Lepidoptera) are the insects," says Kellogg, "most favored of collectors and nature lovers; a German amateur would call them the "Lieblings-insekten." The beautiful color patterns, the graceful flight and dainty flower-haunting habits, and the interesting metamorphosis in their life history make them very attractive, while the comparative ease with which the various species may be determined, and the large number of popular as well as more technical accounts of their life which are accessible for information, render the moths and butterflies most available, among all the insects, for systematic collecting and study by amateurs."

This great group of insects ranks with the beetles and flies in abundance and variety. Between six and seven thousand species are found in North America alone, but they are even more numerous and varied in tropical regions. They attain their greatest size and beauty of color and pattern in the equatorial forest regions, especially in South America.

The exquisite color patterns are due to the covering of minute scales over wings and body. The scales, which are to be regarded as modified hairs, vary in shape and size from (1/350 to 1/30 inch) and their brilliant metallic colors are mainly due to diffraction of light from their finely striated surfaces, while the black, brown, yellow and dull red colors are due to pigment-color in the scale itself. In this group are to be found the most striking examples of protective coloration, of warning colors, of mimicry, and other more obscure phases of adaptive coloration.

The Lepidoptera all undergo a complete metamorphosis, and their caterpillars are more familiar objects than the larvæ of any other group of insects, as they live mostly on green leaves and are active and voracious feeders. Owing to their habits and numbers, many of the larvæ rank among the plagues of farmer, gardener or tree-grower. The adults, mostly nectar-sipping, are harmless as they are often beautiful. The silk-moth, from whose cocoons the world's supply of silk is obtained, is also of high economic importance. The annual production of raw silk is estimated at over $100,000,000. Yet this is but small, probably, compared with the total amount of damage done to gardens, orchards and fields by the depredations of the various caterpillars of one kind or another.

Among butterflies the palm is generally given to the giant Morphos and their relatives, whose brilliant metallic colors brighten the gloomy recesses of the Brazilian forests. These, like many other inhabitants of the deep forest, habitually fly far above the ground, among the tree-tops, and are consequently more difficult to secure. In temperate climates the swallow-tailed butterflies, "Papilio" and its relatives, are the most widely admired. One of the most familiar of the larger butterflies is the "monarch," which owes its success in life partly to its secreting an acrid, ill-tasting fluid that causes birds to let it severely alone. This butterfly is closely mimicked by another, the "viceroy," which is not ill-tasting, but doubtless profits by this resemblance in escaping the attacks of birds.

The order Hymenoptera, in which are included Ants, Bees and Wasps, is the most interesting group among all the lower animals, because many of its members have a highly complicated and elaborated communal life. The study of these great insect societies, of their social life, habits and instincts, is one of the most interesting subjects in the whole range of natural history. From the days of Solomon the tireless industry and frugality of the ant have been proverbial. The busy ways, the complicated and orderly activities of the bee, are familiar to every one, and Maeterlinck's brilliant and sympathetic description of the life of the great bee communities in his "The Life of the Bee," altho perhaps too much tinged with the natural tendency to interpret it in terms of human reason and sensations to be wholly reliable, is one of the most fascinating chapters of natural history ever written.

Besides these better known social insects the Hymenoptera include a variety of solitary forms, saw-flies, gall-flies and ichneumons, and among the bees and wasps there are all degrees of social organization, from solitary to highly elaborated social types. It is especially through the study of these various grades of organization that an understanding can be obtained of the true meaning of many features of the social life of ants and bees, and of how they were developed.

In order to appreciate the character and limitations of their social life, it is necessary first to get some insight into the nature of this intelligence. The nervous system in insects and crustaceans consists of a double cord on the ventral side of the body with paired nodes or ganglia at each segment from which the nerves are distributed, and a pair of principal ganglia on the dorsal side of the head connected with the ventral system by a ring of nerve fibers encircling the gullet. In the higher insects the dorsal ganglia of the head are expanded into a small mass which corresponds in the main with the brain of the higher animals. But the ventral ganglia also perform part of the functions which in the vertebrates are concentrated in the brain, and the relative size and complexity of the brain mass in insects is by no means to be compared with any of the higher vertebrates. The deficiency is especially in the parts corresponding to the cerebrum lodging the higher intelligent and reasoning powers, the automatic and instinctive acts being governed mainly by the enlarged ventral ganglia.

So far as can be judged, the nervous system of an insect is that of a very elaborate and perfect animal automaton, but not much more. It is natural to suppose, on seeing the complex and varied activities of an ant or bee community, that these insects must possess an intelligence comparable with that of man rather than of the lower animals; and ideas of their life are apt to be colored by this view. But the most eminent modern authorities on their psychology, among whom Professor Forel may be especially mentioned, believe that, while not devoid of intelligence, their actions are in the main instinctive and automatic, and that even their intelligent action degenerates into habit—that is, tends to become automatic—much more rapidly than in higher animals.

The extreme complexity of these instincts can be better understood if it is remembered that the insects are a very ancient group. Little of their early history has been definitely ascertained, but the lower orders of insects, at least such as cockroaches and dragon-flies, appeared far back in the age of invertebrates, almost as early as the beginning of the geologic record; and the higher orders are known to have existed at a time when highest vertebrates had not advanced beyond the modern salamanders and newts. During the millions of years since that time, while the vertebrates were slowly developing an intelligent brain, the higher insects were elaborating an instinct brain.

The most serious difficulty in understanding the actions of insects is that their senses are so different from those of Man. Broadly speaking, indeed, they make use of the same media of communication with the outer world. All of them have organs sensitive to ether rays of light and heat, corresponding to human eyesight and to the sense of heat and cold. Most of them have apparatus to sense the waves of sound, altho less developed than the ears of vertebrates, and different in mechanism. All of them have organs for perception of solid bodies and of the minute particles given out from them, corresponding to the senses of touch, taste and smell, but differently situated and combined, and generally much more elaborated. The antennæ of insects are sensitive to touch and odor, and in most of the higher insects are highly specialized organs. In the ants especially they usurp the place which in most animals is taken by the eyes.

"Picture to yourself," says Forel, "an olfactory sense—*i.e.*, a chemical sense effective at a distance and, like our sense of smell, capable of receiving impressions from particles of the most diverse substances diffused through the atmosphere—located not on your nostrils but on your hands. For of such a nature is the position of the olfactory sense on the antennal club of the ant.

"Now imagine your olfactory hands in continual vibration, touching all objects to the right and to the left as you walk along, thereby rapidly locating the position of all odoriferous objects as you approach or recede from them, and perceiving the surfaces both simultaneously and successively as parts of objects differing in odor and position. It is clear from the very outset that such sense organs would enable you to construct a veritable odor-chart of the path you had traversed and one of double significance: (1) A clear contact-odor chart, restricted, to be sure, to the immediate environment, and giving the accurate odorform of the objects touched (round odors, rectangular odors, elongate odors, etc.), and, further, hard and soft odors in combination with the tactile sensations; (2) a less definite chart which, however, has orienting value for a certain distance, and produces emanations which we may picture to ourselves like the red gas of bromine which we can actually see.

"If we have demonstrated that ants perceive chemical qualities through their antennæ both from contact and from a distance, then the antennæ must give them knowledge of space, if the above formulated law is true, and concerning this there is little doubt. This must be true even from the fact that the two antennæ simultaneously perceive different and differently odoriferous portions of space. They must therefore also transmit perceptions and topographically associated memories concerning a path thus touched and smelled. Both the trail of the ants themselves and the surrounding objects must leave in their brains an odor-image of immediate space, and this must render associated memories possible. Thus an ant must perceive the forms of its trail by means of smell. This is impossible, at least for the majority of the species, by means of the eyes."

It will appear therefore that this antennal sense, which Forel designates as topographical, is the principal means by which the brain of the ant is placed in communication with the outside world, supplying the space and form perceptions in the same way that a vertebrate's eyes do. Light and darkness are indifferent to an ant, so far as getting about is concerned. Many of the species use their eyes, but do not depend primarily on them; others are blind or nearly so. This topochemical sense is present in other insects to a varying extent. In Bees and Wasps it is well developed, altho not to the exclusion of sight as in Ants. In Flies and Dragon-flies and in most of the lower insects it is more or less rudimentary; they depend chiefly upon the eyes.

There are other wide differences in the external sense organs of the various insects from man and from each other. Insects see colors differently; they hear sounds to which the human ear is not sensitive, while they are deaf to tones that it perceives. Their world of perceptions is so different in its nature and its limitations that it is difficult to enter very far into the psychology even of their simplest sensations. For the most part the facts can only be related as they appear; the ever-present temptation to interpret the actions of an insect in the terms of the observer's sensations is almost sure to lead him astray.

In most of the lower animals the young are well able to take care of themselves. In general they develop from the egg with little or no help from their parents. But in the Hymenoptera, as in birds and mammals, the young are helpless larvæ, unable to forage for themselves, and requiring to be supplied with food, or fed directly, by the adults. This is the most important fact in the life history of these insects. It differentiates them as of distinctly higher type than any other invertebrates, and it is around the care of the young that their social life chiefly centers. It has been well observed that in man the duration and helplessness of infancy is in direct proportion to the progress of civilization. It is equally true of the lower animals, that those in which the young require and obtain the help of their parents in their early life are thereby enabled to reach a higher stage in development than those in which the young can and do shift for themselves from the time they emerge from the egg.

All of the Hymenoptera make provision in one way or another for their young, and the extent to which this care is carried is the index of development in the different groups.

The Saw-flies, the lowest member of the group, merely place the eggs in favorable spots on the stems of plants, where the larvæ can feed readily upon the juices of the plant. These larvæ are little more helpless than true caterpillars and feed in much the same way.

The Gall-flies show the next stage in progress; the eggs are laid in the leaves or stems of various plants in such a position that the irritation of their presence stimulates the plant to develop abnormal growths or galls, which are utilized as food by the larvæ.

The Ichneumon-flies lay their eggs in the bodies of caterpillars, and the larva develops at the expense of its unfortunate host. A great variety of the lower Hymenoptera are parasitic in this way upon other insects of various orders, and the parasitism has entailed more or less degeneracy. The life histories of these various parasitic forms form a very curious and interesting chapter in natural history.

CHAPTER V

INSECT SOCIAL COMMUNITIES

The study of the habits of Solitary Wasps and Bees and the transitional forms between these and the social kinds gives the clue to the method of development of these great insect societies and helps to explain many features of their life otherwise incomprehensible. In the first place, it is evident that their activities center largely around the care for the young. The larva develops from the egg as a helpless footless maggot, unable to forage for itself, unable to protect itself from enemies. It is dependent among Bees and Wasps upon the food supply stored up in the cell with the egg; among Ants it is fed directly by the workers by regurgitation from their crops.

Solitary Wasps form a group to be considered by themselves. Thus the Digger-wasp ("Sphex") does not live in communities, but the females make separate nests, one for each egg, provisioning them with insect prey which they sometimes kill, but more generally merely paralyze beforehand by stinging them. J. H. Fabre describes their habits in his "Insect Life" as follows:

"The nests may be of mud and attached, for shelter, under leaves, rocks or eaves of buildings, or may be burrows hollowed out in the ground, in trees or in the stems of plants. The adult wasp lives upon fruit or nectar, but the young grub or larva must have animal food, and here the parent wasp shows a rigid conservatism, each species providing the sort of food that has been approved by its family for generations, one taking flies, another bugs, and another beetles, caterpillars, grasshoppers, crickets, locusts, spiders, cockroaches, aphids or other creatures, as the case may be.

"The Solitary Wasps mate soon after leaving the nest in the spring or summer. The males are irresponsible creatures, aiding little, if at all, in the care of the family. When the egg-laying time arrives the female secures her prey, which she either kills or paralyzes, places it in the nest, lays the egg upon it, and then in most cases closes the hole and takes no further interest in it, going on to make new nests from day to day. In some genera the female maintains a longer connection with her offspring, not bringing all the provisions at once, but returning to feed the larva as it grows and only leaving the nest permanently when the grub has spun its cocoon and become a pupa.

"The egg develops in from one to three days into a footless maggot-like creature which feeds upon the store provided for it, increasing rapidly in size and entering the pupal stage in from three days to two weeks. In the cocoon it passes through its final metamorphosis, emerging as a perfect insect perhaps in two or three weeks, or, in many cases, after the winter months have passed and summer has come again. Probably no Solitary Wasp lives through the winter, those that have come out in the spring or summer perishing in the autumn."

"The habit common to almost all of the Solitary Wasps," says Kellogg, "of so stinging the prey, caterpillars, spiders, beetles, flies, bugs, or whatever other insects are used to provision the nests, as not to kill but only to paralyze it, is perhaps the most amazing part of all the interesting behavior of all these wasps. The advantage is obvious: killed, the prey would quickly decompose, and the hatching carnivorous wasp larva would have only a mass of, to it, inedible decaying flesh, instead of the fresh live animal substance it demands. But if stored unhurt, the prey would, if a cricket or spider or similarly active animal, quickly escape from the burrow, or if a caterpillar or weak bug, at least succeed, albeit unwittingly, in crushing the tender wasp egg by wriggling about in the underground prison cell.

"More than that, unhurt, some insects could not live without food the many days that are necessary for the development of the wasp larva, especially in the face of the frantic and exhausting efforts they would be impelled to in their attempts to escape. But paralyzed, there is no exertion; metabolism is slight, and life without food is capable of being prolonged many days. The paralysis is due to the stinging by the Wasp of one or more of the ganglia (nerve centers) of the ventral nerve cord. The amazing expertness and accuracy displayed in plunging the sting into exactly those spots where injury will give rise to exactly that physiological phenomenon in the prey that will make it available for the special conditions attending the wasp larva's sustenance—this adroitness and this seeming knowledge of the structure and the physiology of the prey have led some entomologists to credit the Solitary Wasp with anthropomorphic qualities that are quite unwarranted. The whole behavior is probably explicable as a complex and advantageous reflex or instinct, developed by selection.

Similarly, the whole course of the nest building and provisioning is an elaborate performance wholly for the sake of the young, which the mother will likely never see; and these young in turn will, if females, do the same thing, perfectly, and in essentially, if not exactly, the same manner, without ever previously seeing such remarkable processes performed. All these complex and altruistic habits have naturally led to much speculation concerning their origin and their relation to psychical conditions. Whether a consciousness of what is being done and an intelligence is brought to bear upon its doing; whether we may attribute to the wasp a psychical state, with its attributes of cognizance, reason and emotion—these are questions which are debated warmly. The consensus of opinion, however, is distinctly adverse to reading into the behavior of "Ammophila" or any of its allies anthropomorphic attributes of reason, consciousness or emotion. The fixity and inevitableness which is preëminently characteristic of the behavior of the wasps, and the fact that each female is "ab ovo" adequate to carry through the complex train of actions without teaching, experience or opportunity for imitation, practically prove all this seeming marvel of reasoned care for the future young to be an inherited instinct incapable of essential modification except by the slow process of selection through successive generations."

The Social Wasps—Hornets, Yellow-Jackets and such—live in great communities of males, females and a third caste, the neuters or workers. These last are in reality sterile females, taking no part in the reproduction of the race, but take charge of the building and caring for the nest of the community, bringing food and rearing the young.

The life-history of a community in general outline is given by Kellogg as follows: "In the early spring, fertilized females (queens) which have hibernated (as adults) in sheltered places, as crevices in stone walls, under logs, stones, etc., come out from their winter hiding places and each makes a small nest, containing a few brood cells. In each cell an egg is laid, and food, consisting of insects, killed and somewhat masticated, is hunted for and brought to the larvæ throughout their brief life by the queen. The larvæ soon pupate in the cells and in a few days issue as winged wasps. They are exclusively workers. These workers now enlarge the nest, adding more brood cells in which the queen deposits eggs. The bringing of food and the care of the young now devolve on the workers.

"The new, or second, brood also is composed of workers only, and these immediately reinforce the first brood in the work of enlarging the nest and building new brood cells. Thus, through the summer, several broods of workers are reared until in the late summer or early fall a brood containing males and females as well as workers appears. The community is now at its maximum, both as regards population and size of nest. In the species "Vespa," which make the great ball-like aerial nests, the community may grow to number several thousand individuals. The males and females mate (presumably with members of other communities), but no more eggs are laid, and with the gradual coming on of winter the males and workers and many of the females die. There persist only as survivors of each community a few fertilized females. These crawl into safe places to pass the winter. Any Social Wasp found in winter time is thus almost certainly a queen. Those of the queens which come safely through the long winter found the communities which live through the following season.

"The Social Wasps of the genus Vespa, the familiar Yellow-jackets and Hornets, are the ones which build the large subspherical nests familiar to all outdoor observers and related to much boyish adventure. Inside the great globe are several horizontal combs of brood cells in tiers, all enclosed by several layers of wasp-paper. The large bald-faced Hornet, 'Vespa maculata,' is the best known builder of the globe nests. The smaller Yellow-jackets ('Vespa germanica,' 'Vespa cuneata') build in hollows in stumps or stone fences or underground. Such protected or underground nests are not as thoroly or thickly enveloped in paper as are the exposed arboreal globe nests. The miniature queen nests of the 'Vespa,' with the single little brood comb inside, may often be found by careful searching in the spring.

"The long-bodied, blackish Wasps of the genus 'Polistes' build single exposed horizontal combs out of wasp-paper (chewed wood), which are attached to the under side of porch roofs, eaves, ceilings of out-buildings, etc., by a short central stem. The little comb made by the queen may contain but half a dozen cells, but after the workers hatch many other cells are added around the margin. But the nest and workers never compare in size and numbers with the large communities of 'Vespa.'"

Among all the Wasps the adult feeds upon nectar of flowers, but the larva is fed on insects, paralyzed or freshly killed. The Solitary kinds store up food and place it in the cell with the egg; the Social Wasps do not, but the queen at first and afterward the workers forage for insects, which they bring in constantly and feed to the larvæ in a killed and partially masticated condition.

Bees differ from Wasps in that the young larva, as well as the adult, is fed upon the nectar and pollen of flowers, converted into honey and bee-bread, instead of upon insect food as in the Wasps. The structure of the mouth parts and the instincts of the Bee differ accordingly. There are a great many kinds of Solitary Bees, but the Social Bees, the wild Bumblebee and the Hive-bee are by far the most familiar. In the Solitary Bees there are only males and females; in the Social Bees, as in Social Wasps, there are males, females and workers. The Bumblebees nest underground, occupying and enlarging a mouse-hole or small burrow, and the life-history of the community is much like that of the Wasps. They do not make honey cells, but mix pollen and honey to a pasty mass, deposit a few eggs upon the mass, and in the later stages of the nest build waxen cells for the larvæ to pupate in.

The Honey Bees ("Melipona" and "Apis") have a much more elaborated community life, and unlike the Wasps and Bumblebees, this does not terminate with the summer, but is continuous from season to season. The Meliponas are tropical bees, stingless or nearly so, living in immense communities whose life-history is not completely known. The better known Hive-bees ("Apis") are native to the Old World, but domesticated and introduced everywhere. The habits and life-history of the great Hive-bee communities have been more carefully studied than any other phase of insect life. Yet there are many unsolved problems, especially in regard to the interpretation and meaning of their behavior.

A well-written and reliable account of the life of the Hive-bees is given in Jordan and Kellogg's "Evolution and Animal Life," from which the following may be quoted:

"An interesting series of gradations from a strictly solitary through a gregarious to an elaborately specialized communal life is shown by the bees. Altho the Bumblebee and the Honey Bee are so much more familiar to us than other bee kinds that the communal life exemplified by them may have come to seem the usual kind of bee life, yet, as a matter of fact, there are many more solitary bees than social ones. The general character of the domestic economy of the solitary bees is well shown by the interesting little Green Carpenter Bee, 'Ceratina dupla.' Each female of this species bores out the pith from five or six inches of an elder branch or raspberry cane, and divides this space into a few cells by means of transverse partitions. In each cell she lays an egg, and puts with it enough food—flower pollen—to last the grub or larva through its life. She then waits in an upper cell of the nest until the young bees issue from their cells, when she leads them off, and each begins active life on its own account.

"The Mining Bees, 'Andrena,' which make little burrows in a clay bank, live in large colonies—that is, they make their nest burrows close together in the same clay bank, but each female makes her own burrow, lays her own eggs in it, furnishes it with food—a kind of paste of nectar and pollen—and takes no further care of her young. Nor has she at any time any special interest in her neighbors. But with the smaller Mining Bees, belonging to the genus 'Halictus,' several females unite in making a common burrow, after which each female makes side passages of her own, extending from the main or public entrance burrow. As a well-known entomologist has said, '"Andrena" builds villages composed of individual homes, while "Halictus" makes cities composed of apartment houses.'

"The Bumblebee, however, establishes a real community with a truly communal life, altho a very simple one. The few Bumblebees which we see in winter time are queens; all others die in the autumn. In the spring a queen selects some deserted nest of a field mouse, or a hole in the ground, gathers pollen which she molds into a rather large irregular mass and puts into the hole, and lays a few eggs on the pollen mass. The young grubs or larvæ which soon hatch feed on the pollen, grow, pupate, and issue as workers—winged bees a little smaller than the queen. These workers bring more pollen, enlarge the nest, and make irregular cells in the pollen mass, in each of which the queen lays an egg. She gathers no more pollen, does no more work except that of egg-laying. From these new eggs are produced more workers, and so on until the community may come to be large. Later in the summer males and females are produced and mate. With the approach of winter all the workers and males die, leaving only the fertilized females, the queens, to live through the winter and found new communities in the spring.

"The Social Wasps—as with the bees, there are many more kinds of solitary wasps than social ones—show a communal life like that of the Bumble bees. The only Yellow-jackets and Hornets that live through the winter are fertilized females or queens. When spring comes each queen builds a small nest suspended from a tree branch, or in a hole in the ground, which consists of a small comb enclosed in a covering or envelope open at the lower end. The nest is composed of 'wasp-paper,' made by chewing bits of weather-beaten wood taken from old fences or outbuildings. In each of the cells the queen lays an egg. She deposits in the cell a small mass of food, consisting of some chewed insects or spiders. From these eggs hatch grubs which eat the food prepared for them, grow, pupate, and issue as worker wasps, winged and slightly smaller than the queen. The workers enlarge the nest, adding more combs and making many cells, in each of which the queen lays an egg. The workers provision the cell with chewed insects, and other broods of workers are rapidly hatched. The community grows in numbers and the nest grows in size until it comes to be the great ball-like oval mass which we know so well as a hornets' nest, a thing to be left untouched. When disturbed, the wasps swarm out of the nest and fiercely attack any invading foe in sight. After a number of broods of workers has been produced, broods of males and females appear and mating takes place. In the late fall the males and all of the many workers die, leaving only the new queens to live through the winter.

"Honey Bees live together, as we know, in large communities. We are accustomed to think of Honey Bees as the inhabitants of beehives, but there were bees before there were hives. The 'bee tree' is familiar to many of us. The bees, in nature, make their home in the hollow of some dead or decaying tree-trunk, and carry on there all the industries which characterize the busy communities in the hives. A Honey Bee community comprizes three kinds of individuals—namely, a fertile female or queen, numerous males or drones, and many infertile females or workers. These three kinds of individuals differ in external appearance sufficiently to be readily recognizable. The workers are smaller than the queens and drones, and the last two differ in the shape of the abdomen, or hind body, the abdomen of the queen being longer and more slender than that of the male or drone. In a single community there is one queen, a few hundred drones, and ten to thirty thousand workers.

"The number of drones and workers varies at different times of the year, being smallest in winter. Each kind of individual has certain work or business to do for the whole community. The queen lays all the eggs from which new bees are born; that is, she is the mother of the entire community. The drones or males have simply to act as royal consorts; upon them depends the fertilization of the eggs. The workers undertake all the food-getting, the care of the young bees, the comb-building, the honey-making—all the industries with which we are more or less familiar that are carried on in the hive. And all the work done by the workers is strictly work for the whole community; in no case does the worker bee work for itself alone; it works for itself only in so far as it is a member of the community.

"How varied and elaborately perfected these industries are may be perceived from a brief account of the life history of a bee community. The interior of the hollow in the bee tree or of the hive is filled with 'comb'—that is, with wax molded into hexagonal cells and supports for these cells. The molding of these thousands of symmetrical cells is accomplished by the workers by means of their specially modified trowel-like mandibles or jaws. The wax itself, of which the cells are made, comes from the bodies of the workers in the form of small liquid drops which exude from the skin on the under side of the abdomen or hinder body rings. These droplets run together, harden and become flattened, and are removed from the wax plates, as the peculiarly modified parts of the skin which produce the wax are called, by means of the hind legs, which are furnished with scissor-like contrivances for cutting off the wax.

"In certain of the cells are stored the pollen and honey, which serve as food for the community. The pollen is gathered by the workers from certain favorite flowers and is carried by them from the flowers to the hive in the 'pollen baskets,' the slightly concave outer surface of one of the segments of the broadened and flattened hind legs. This concave surface is lined on each margin with a row of incurved stiff hairs, which hold the pollen mass securely in place.

"The 'honey' is the nectar of flowers which has been sucked up by the workers by means of their elaborate lapping and sucking mouth parts and swallowed into a sort of honey-sac or stomach, then brought to the hives and regurgitated into the cells. This nectar is at first too watery to be good honey, so the bees have to evaporate some of this water. Many of the workers gather above the cells containing the nectar and buzz—that is, vibrate their wings violently. This creates currents of air which pass over the exposed nectar and increase the evaporation of the water. The violent buzzing raises the temperature of the bees' bodies, and this warmth given off to the air also helps make evaporation more rapid. In addition to bringing in food, the workers also bring in, when necessary, 'propolis,' or the resinous gum of certain trees, which they use in repairing the hive, as closing up cracks and crevices in it.

"In many of the cells there will be found, not pollen or honey, but the eggs or the young bees in larval or pupal condition. The queen moves about through the hive, laying eggs. She deposits only one egg in a cell. In three days the egg hatches, and the young bee appears as a helpless soft, white, footless grub or larva. It is cared for by certain of the workers, that may be called nurses. These nurses do not differ structurally from the other workers, but they have the special duty of caring for the helpless young bees. They do not go out for pollen or honey, but stay in the hive. They are usually the new bees—*i.e.*, the youngest or most recently added workers. After they act as nurses for a week or so they take their places with the food-gathering workers, and other new bees act as nurses. The nurses feed the young or larval bees at first with a highly nutritious food called bee jelly, which the nurses make in their stomach and regurgitate for the larvæ. After the larvæ are two or three days old they are fed with pollen and honey. Finally, a small mass of food is put into the cell, and the cell is 'capped' or covered with wax. Each larva, after eating all its food, in two or three days more changes into a pupa, which lies quiescent without eating for thirteen days, when it changes into a full-grown bee. The new bee breaks open the cap of the cell with its jaws and comes out into the hive, ready to take up its share of the work for the community.

"In a few cases, however, the life history is different. The nurses will tear down several cells around some single one, and enlarge this inner one into a great irregular vase-shaped cell. When the egg hatches, the grub or larva is fed bee jelly as long as it remains a larva, never being given ordinary pollen and honey at all. This larva finally pupates, and there issues from the pupa not a worker or drone bee, but a new queen bee. The egg from which the queen is produced is the same as the other eggs, but the worker nurses by feeding the larva only the highly nutritious bee jelly make it certain that the new bee shall become a queen instead of a worker. It is also to be noted that the male bees or drones are hatched from eggs that are not fertilized, the queen having it in her power to lay either fertilized or unfertilized eggs. From the fertilized eggs hatch larvæ which develop into queens or workers, depending on the manner of their nourishment; from the unfertilized eggs hatch the males.

"When several queens appear there is much excitement in the community. Each community has normally a single one, so that when additional queens appear some rearrangement is necessary. The rearrangement comes about first by fighting among the queens until only one of the new queens is left alive. Then the old or mother queen issues from the hive or tree followed by many of the workers. She and her followers fly away together, finally alighting on some tree branch and massing there in a dense swarm. This is the familiar phenomenon of 'swarming.' The swarm finally finds a new hollow tree, or in the case of the Hive-bee the swarm is put into a new hive, where the bees build cells, gather food, produce young, and thus found a new community. This swarming is simply an emigration, which results in the wider distribution and in the increase of the number of the species. It is a peculiar but effective mode of distributing and perpetuating the species. The community, it is important to note, is a persistent or continuous one. The workers do not live long, the spring broods usually not over two or three months, and the fall broods not more than six or eight months; but new ones are hatching while the old ones are dying, and the community as a whole always persists. The queen may live several years, perhaps as many as five. She lays about one million eggs a year."

The Ants may fairly be regarded as the highest group of invertebrate animals. They excel in the variety and complexity of their instincts and the elaborateness of their social organization, and their abundance and wide distribution mark them as one of the most successful and dominant types produced by evolution.

There are no solitary ants. All of them have a highly complex social life, live in large communities composed of males, females and workers. The workers (sterile females) are the principal part of an ant colony; only at the mating season do males and females appear in any considerable numbers. The workers are wingless and much smaller than the males and females; the latter are winged only for the mating or swarming season, when they leave the nest. After mating the males die and the females or queens, throwing off their wings, proceed each to found a new colony.

Aside from their mating flights, Ants are all strictly terrestrial. Their nests are a maze of underground galleries and chambers tunneled out by the workers and serving as a retreat for the adults, a nursery for the young, a granary for stored-up food, and in one group of Ants as a vegetable garden as well. The colony consists usually of a queen-ant, or in some instances several queens, whose duties are confined to egg laying, of a great number of workers of two or more castes, worker-minors, worker-majors and sometimes soldiers, and at certain seasons of the winged males and females ready to issue from the nest, mate and form new colonies. The duties of the different castes of workers vary; to the youngest and smallest ones are assigned the care of the eggs and feeding of the larvæ; the larger workers forage for food; while the soldiers, large-headed and with powerful jaws, apparently do little besides protecting the nest in case of attack.

Ants are primarily carnivorous; they subsist on other insects or upon sweet juices exuding from flowers, leaves or stems or secreted by insects. They are extremely fond of the "honey-dew" secreted by the plant-lice, or Aphids, which with many of the common species forms an important part of their food. On every plant infested by Aphids one is pretty certain to see a number of Ants in attendance, stimulating the excretion of the honey-dew by deft stroking. Many are the stories that have been told of the curious relations between Ant and Aphis, but many of them need to be verified by more careful investigation. Nevertheless it is certain that the Ants do take care of their "cows," as Linnæus called them, in a way that is at least suggestive of domestication. If the various Ants attending Aphids on one plant are observed, they will be found to be all of one species and apparently all from one nest. One might assume from this, but probably quite incorrectly, that Aphids were considered as personal (or rather municipal) property among the Ants. Again, certain Ants build a sort of tent of mud or vegetable fiber over parts of branches or stems infested with Aphids or scale insects, and this tent serving to protect and shelter both the Ants and their "cows" from rain or from incursions of enemies or other ants, may fairly be regarded as a stable. Furthermore, in at least one common species of Ant, the workers have been seen to take the newly hatched Corn-root Aphids and carefully place them upon the roots of certain species of knotweed, guard and protect them there until the corn-roots were sufficiently advanced and then to remove the Aphids to feed upon the corn. There can be no question that the mere presence of such bold, active and efficient fighters as the Ants must serve to keep away enemies from the slow and helpless Aphids; but to what further extent the Ants actively protect their charges is not so clear.

The most familiar traditional aspect of ant life, the storing up of grain for a winter supply, is illustrated in the Harvester or Agricultural Ants, whose nests are conspicuous in open grassy places and especially in arid or nearly desert regions. They bring into their nests great quantities of grain and grass seeds, and have been even credited with deliberate planting for harvest of certain kinds of grass seed, of which they are very fond; this last, however, is discredited by Wheeler.

The Ecitons, or Foraging Ants, are fierce predatory insects, well known in West Africa and tropical America. They are nomadic, having no fixed habitations but travel mostly by night in enormous armies which seek out and destroy every living animal in their path. The approach of these great columns strikes terror and confusion into all the varied life of the tropical forests. Beast, bird and man hasten to get out of their path. Dwellings are promptly vacated on notice of their appearance, and they swarm through the house, seek out every cranny and crevice, attack and tear to pieces insects, mice, rats and vermin of every kind, and retire, loaded with booty to their nests, which are mere temporary camps excavated beneath stones or other convenient shelter.

They are blind or nearly so, and traveling chiefly by night, are guided by their antennal sense, which, as in most other ants, practically takes the place of sight in higher animals. Travelers in the forest whose camps are in the line of march of an army of Driver Ants find themselves suddenly covered by swarms of big black insects, biting fiercely at every unprotected spot, and have to run for their lives, abandoning camp baggage and clothing for a time to the mercies of their savage assailants. Their household visitations are regarded as a blessing, for the dwelling is clear of vermin, dead or alive, when they get through with it, and a temporary eviction is a small price for the owners to pay where vermin swarm as they do in the tropics.

The Saübas, or Leaf-cutting Ants, are among the most remarkable of all the social insects. They are abundant in tropical America and species of this group are found as far North as New Jersey. In South and Central America they build enormous nests with vast ramifications of galleries and passages which extend for many yards and are even said to tunnel under considerable rivers. Their curious habit of cutting out little pieces of leaves and carrying them to their nests was noticed by early explorers and is referred to even in some of the Indian legends. But it was long a mystery what they did with the leaves. Ants generally are dependent for food upon other insects, animal matter or upon sweet juices which they obtain in various ways. They do not usually eat ordinary vegetation, and while the Saübas might be supposed an exception to the rule, there was no evidence that they ate the leaf fragments which they so carefully conveyed to their homes. Professor Bates, who saw their work in the Amazon Valley, was of the opinion that they used the leaves to thatch their galleries and protect them from the heavy tropic rains. The true explanation was suggested in 1874 by Thomas Belt.

The leaves are used as manure in which they grow and cultivate a peculiar species of fungus on which they feed. Within the nests, several feet below the ground, they excavate large cavities, often a foot in diameter, which are veritable underground gardens, tended, weeded and manned by different grades of workers. The little leaf fragments are brought to these cavities, cut, crushed and manipulated into small round pellets, and planted in the surface of the garden, to serve as nutriment for the fungus to grow upon. Under the care of the ants the fungus is not allowed to produce spores, but only to grow in thread-like filaments, from which clusters of transparent globules bud off, these latter forming the food of the ants. All other kinds of fungus growth are carefully kept down, and the temperature and moisture of the fungus garden is regulated by opening or closing the openings at the top of the nest, which seem to be chiefly ventilation holes, the Ants issuing and returning by other openings more or less distant.

"These insects," observes Wheeler, "in the fierce struggle for existence everywhere apparent in the tropics, have developed a complex group of instinctive activities which enables them to draw upon an ever-present, inexhaustible food supply through utilizing the foliage of plants as a substratum for the cultivation of edible fungi. No wonder, therefore, that, having emancipated themselves from the precarious diet of other ants, which subsist on insects, the sweet exudations of plants and excrement, the Attii have become the dominant invertebrates of tropical America."

The nests are guarded by large soldier-workers, with massive heads and powerful jaws. Smaller workers of several different sizes have assigned to them the various tasks of collecting leaves, of excavating the tunnels and galleries, of cultivating, manuring and weeding the fungus and of feeding the young, helpless larvæ, the nurse-girls of the colony being the smallest and youngest of the workers. Upon leaving the nest for the foundation of a new colony, the female carries with her a small pellet of the fungus, which is carefully tended and manured until the new colony has become established.

The Saüba Ants are not the only fungus-growing insects. Among the Termites, which, altho not true Ants, resemble them in appearance and social habits, there are certain kinds that also cultivate a species of fungus which they use for food. The worker sex, however, is said to feed upon dead wood and to receive no share of the fungus which it spends so much time in cultivating. Among the wood-boring beetles the Ambrosia Beetles also cultivate and feed upon certain kinds of fungus, growing it on the walls of the galleries which they excavate.

The Honey Ants ("Myrmecocystus") are a unique group. These curious little Ants store up honey like the Bees, but in a very different way. Instead of building cells of wax, they store it up in the bodies of certain of the workers, in which the abdomen becomes enormously distended, so that they are veritable living casks. These individuals do not leave the nests, but are fed by the active workers, and when replete, hang from the roof of enlarged chambers in the runways. In seasons of scarcity they are able to turn to feed the rest of the community by the same method of regurgitation. They inhabit the arid southwestern United States and were studied and described by Professor McCook from the Garden of the Gods in Colorado. Leading a rather precarious existence in a region where food is abundant only for a short season in the year, the advantage of this habit can readily be seen, and there are certain advantages about living casks in being more readily removed from danger than the fixed storehouses of the Bees.

A curious development of the social life of Ants is seen in the so-called Slave-making Ants. Two of these, the Sanguinary Ant, or Red Slave-maker, "Formica sanguinea," and the Amazon Ant, "Polyergus," are well known, and their habits have been carefully studied, the most recent studies and interpretation being by Wheeler. The Sanguinary Ant makes raids upon the nests of other ants, but in particular upon the smaller brown species, "Formica fusca," killing the workers, carrying off eggs and larvæ to its own nest. Most of the larvæ are used for food, but a part of them are reared and brought up in the nest of their captors. They become loyal members of the new community and take part in the multifarious activities of the nest, going out in search of food, caring for the eggs, feeding the larvæ, excavating or extending the nest and so on. It does not appear that they take part in the raids on other ant nests, but probably this is merely because such raids are conducted by the larger and more powerful workers only in any ant community.

The resemblance here to slave-making in the human race is more superficial than real. Worker-ants are never captured in these raids, and the larvæ reared in the nest of the captors are not an unwilling and inferior race forcibly held in subjection and treated as an inferior caste. The nest is rather to be considered as a mixed community, in which the division of labor is based on the capabilities of the individual, but not on his race. Nevertheless, if it is considered that it is only the worker larvæ of the smaller species that are reared, and that they help to rear and care for the young of an alien race instead of their own, this slave-making does involve the exploiting of the weaker for the benefit of the more powerful race.

In the Amazon Ant a further development of the slave-making instinct appears, which may serve to show where the weak point lies in this method of exploitation. In this species the workers have become largely dependent upon the captured race, not only for the care of the nest and rearing of the young, but for food as well, so that they are unable to feed or groom themselves. Under these conditions the continuance of the Amazon Ant communities obviously becomes dependent upon the prosperity and abundance of colonies of the smaller species. The slave-making race cannot prosper at the expense of the other beyond a certain limit, and its relations tend to become analogous to those of parasitic animals.

In several kinds of ants the female, instead of depending upon her own progeny to start a new colony, may seek out a small existing colony of her own or some other species and persuade or compel the workers to adopt her. This process has been carefully observed by Wheeler and distinguished from the slave-making habits with which it might readily be confused. Both result in mixed communities in which the larger species is more or less dependent upon the smaller in its household and personal activities. But the slave-making results from the carrying off of larvæ from raided nests; the social parasitism from the adoption by an ant community of a queen of alien race. It is not wholly clear, in spite of the careful observations of Wheeler and others, how the invading queen manages to overcome the strong instinct of antagonism in the workers to an ant of another community or race. But this parasitism is carried in some species so far that the invading race has no workers, only males and females, and is wholly dependent upon its host for sustenance.

There is a great variety of parasitism, social and individual, to be seen in ant communities, and the careful study of its nature has thrown much light on the nature and limits of the intelligence of these insects. There are several kinds of smaller ants that live in mixed communities with larger forms, but construct separate galleries opening into the larger galleries of their hosts, but too small for the larger ants to traverse. Among these some, like the Thief Ant, "Solenopsis," prey upon the larvæ and pupæ of the larger form, while others merely levy toll upon the supplies brought in by the larger workers.

Again there are various insects of other orders, flies, bugs and spiders, which make their homes in ant nests. Some are harmless, or even beneficial in the life of the community, but others are ravenous and destructive enemies of the ants, preying upon the eggs or larvæ, laying their own eggs within the ant-larvæ to develop at their expense, and in various ways seriously interfering with the prosperity of the nest. Yet the eggs and larvæ of these parasites are as carefully tended and reared by the ants as their own, and the adults are evidently tolerated by the workers, either because they are unobserved, or because they are regarded as nest-mates, or for some other reason still obscure.

CHAPTER VI

THE VERTEBRATES—I. FISH

The vertebrates, or backboned animals, including fish, amphibia, reptiles, birds and mammals (with man), are markedly differentiated in their plan of organization from the radiates, mollusks or arthropods. This new plan of organization, leading to a higher plane of development, has made the vertebrate the dominant type of animal life, not indeed in numbers of individuals or species, as some naturalists would interpret dominance, but as individually higher types, better fitted for success in the struggle for existence. They have further opened the way, in the development of man, for the inception of a new era, the Psychozoic Era as it has been aptly called by Leconte, in which intellect becomes the principal factor in the evolution of life, controlling its environment, guiding its development, and leading to results which we can but dimly foresee, even as to those immediately before us.

In a brief review of the plan of organization of the vertebrates it will appear wherein these advantages lie. In all vertebrates there is an internal skeleton, of which the central feature is the backbone, originally developed from the "notochord," a segmented strip of cartilage later converted into bone, forming the nucleus of the spine. This internal skeleton, as against the external skeleton of most invertebrates, affords certain marked mechanical advantages in giving the muscles a better purchase and enabling them to control the action and movements of body and limbs more powerfully. Now it is a fundamental fact of mechanics that with every doubling of the dimensions of a structure the relative strength of its materials is reduced by one-half. So that larger constructions, to perform what is relatively the same work, must be more massively proportioned, or made of stronger material than smaller ones. This is equally true of animals. The larger an animal is the more powerful and strongly constructed must it be, in order to have the same amount of activity and obtain its proportional amount of food. It is a common saying that if a flea were the size of an elephant he could jump over the spire of the highest cathedral in Europe. But any engineer can see the absurdity of this statement. If a flea were the size of an elephant, he would in fact be unable to lift his body off the ground. His proportionate strength would be 1-4320 of what it is, and in all probability would not hold his body together. His apparent strength is merely due to his minute size. If vertebrates and invertebrates of equal size be compared the greater strength and activity of the vertebrate is immediately perceived.

Now size is a very important factor in the dominance of an animal, and the superior organization of the vertebrates which has enabled them to attain much larger size is in no small degree due to their having an internal skeleton. Many vertebrates have also developed for protection an external skeleton of scales or plates, and the most ancient of fossil vertebrates were well armored externally, while the internal skeleton was still composed of cartilage not yet hardened into bone.

The nervous system of vertebrates consists of a spinal cord along the back just above the notochord, and a brain developing at the front end of the notochord. The brain is more concentrated into a single mass than in invertebrates, where its functions are partly distributed among ganglia in different parts of the nervous cords. This naturally makes for more centralized and better correlated control of the different parts and organs of the body, and facilitates the development of intelligence and reasoning powers. In the highest invertebrates there is a marvelous development of accurately coördinated automatic action and complexity of instinct, but they seem to be unable to attain high intelligence or reasoning powers. In vertebrates, while the instincts are less elaborate and complex, the observer is impressed with the relatively intelligent character of their activities, with their ability to respond to new sensations, and accommodate themselves to new conditions of life. This is to be connected with their more concentrated brain, and from the first the nervous system appears to have been more concentrated in vertebrates than in any of the invertebrate groups.

All vertebrates breathed primarily by gills, the water which aerated the gills entering through the mouth and making its exit through gill-slits on each side of the throat. Fishes and tadpoles still breathe this way, but land animals have become adapted to breathing air by means of the lungs. Rudimentary lungs are present in many primitive fishes, serving to assist the gills in aerating the blood when, as in stagnant ponds, the supply of oxygen in the water was not sufficient for the needs of the fish. In the more typical modern fish this rudimentary lung has been converted into the so-called swim-bladder, serving to adjust the weight of the body to the water around by compressing or expanding the air contained in it, and perhaps for adjusting the amount and quality of air in the blood. It is interesting to observe that the embryos of all land mammals, including man, pass through a stage in which they possess gill-slits, altho these serve no purpose in the life of the young animal.

All vertebrates except certain very lowly types possess paired appendages—fins, limbs or wings. These consist always of two pairs, never more, and originate in an entirely different way from those of arthropods, as folds of skin along the side of the body, becoming concentrated into fins or paddles and thence converted into limbs. In birds, bats and pterodactyls the fore limbs are converted into wings.

The alimentary or digestive system consists at first of a long straight canal near the under side of the body and is elaborated into a very complex affair by the development of various glands to assist in digestion, and by the lengthening and coiling of the alimentary canal. The circulatory system is much more elaborated than in the lower animals and progressively so in the higher vertebrates. A marked difference from insects lies in the fact that air is conveyed from the lungs or gills to the tissues by medium of the blood corpuscles, whereas in insects the air reaches the tissues of all parts of the body directly through the tracheæ. The circulation of the blood is thus a much more important function of the life of vertebrates than of insects.

In the development of the skeleton it is to be noted that the spinal cord soon becomes arched over by segments of bone and the brain enclosed in a bony capsule; that the under side of the body is supported by arches of cartilage from each segment of the notochord, which are converted into bony ribs; that the gill-arches are also supported by bony arches, of which the front pair is later converted into a part of the lower jaw; that the teeth develop originally as scales on the skin of the mouth; that the segmented limb-bones retain even among mammals many suggestions of their former fin-ray construction. Various additional bones are formed in the skin of the head which coalesce with the more internal bones of brain capsule and jaw to form the solid skull of the higher vertebrates. In fishes the various bones of the head are more or less separate, as also in the young of higher animals.

The eyes are in general highly developed and are the most important of the sense organs; the hearing organs are also very elaborate and complicated. The sense of smell, altho usually well developed, has by no means the importance that it reaches among the higher insects.

The vertebrates were, at first and for a long time, adapted to live in water. In reviewing the geological history of the different groups, the successive stages of their invasion of the land and adaptation to terrestrial life will appear. Having once become well adapted to air-breathing and the more active and varied life of the dry land, the vertebrates were enabled, through their better plan of organization, to attain larger size and higher intelligence than the insects, spider and land snails which were their predecessors as land animals. Their internal instead of external skeleton, their more concentrated nervous system, and it might be added, their more concentrated breathing system (for the tracheæ of insects may be regarded as lungs distributed throughout the whole body) were probably the principal points of advantage.

Vertebrates are much less ancient than the invertebrate groups. At the beginning of recorded geological history the several groups of invertebrates already were well specialized. They must have had a long previous era of evolution of which there is no record, partly because the most ancient rocks containing it are so altered by crystallization that their fossils have been destroyed, partly because many or all of these most ancient animals possessed no hard points which could be preserved as fossils. But the earliest vertebrates, appearing about the middle of the Paleozoic era, are only beginning to assume the distinctive characters of vertebrata, so far as can be judged from the fossil remains. They were in the dawn of their development; and as they are followed upward in the geologic column, they are found putting on more and more of the characteristic features of vertebrata, and finally, at the end of the long Paleozoic era, becoming adapted, at first very imperfectly, for active land life.

The earliest vertebrates had a notochord but no bony internal skeleton; but some of them had a very complete bony armor. The notochord was gradually replaced by a true backbone in the land vertebrates, but more or less of it still remains in modern fishes, and it was not until the beginning of the Age of Reptiles that it disappeared among the land vertebrates.

Among these most ancient of vertebrates may be mentioned two groups, the Ostracoderms, covered with bony armor (or sometimes with only the head armored), first found in the Old Red Sandstones of Scotland, of whose "griesly fisch in the laithly flood" Hugh Miller has given such lively and fascinating descriptions. These animals at first glance resemble crustaceans or scorpions, but they are considered as vertebrata, altho not true fishes. True fishes appear a little later, in the primitive sharks, and related types which are preserved, sometimes in great perfection, in the Devonian shales of Ohio and elsewhere.

In the sharks and rays the internal skeleton is still composed of cartilage, as it was in the primitive ancestral vertebrates. The gill-slits are also of a very ancient type. They consist of a number of separate slots along the outer surface of the side just behind the head. In all the higher fishes they are covered by a flap of bone and skin called the operculum, or gill-cover.

To the bather in tropical waters, to the shipwrecked seaman clinging to a raft or afloat in a leaky overloaded boat, the appearance of sharks is the danger most to be dreaded. Swift, powerful and voracious, many of them huge in size, they are the terror of the warmer seas. Indiscriminate in their appetite, they are fortunately less dexterous than many other fish in seizing their prey at the surface, and may often be frightened away by splashing and disturbance of the water, which their low intelligence does not allow them to understand. It is probable, indeed, that the number of swimmers actually devoured by sharks is by no means in proportion to their reputation.

The largest and most voracious of the man-eating sharks is the great white shark found in all tropical seas, but fortunately not very common. This species reaches a length of 30 feet, and is quite capable of swallowing a man whole. It is, according to Linnæus, the "great fish" which swallowed Jonah. "Jonam Prophetum ut veteris Herculem trinoctem, in hujus ventriculo tridui spateo bæsisse, verosimile est." Gesner relates that the bodies of men have been found entire in sharks, on one occasion, at Marseilles, a man in complete armor; and over a hundred similar cases "have since been recorded."

Huge as is the living white shark, it was far surpassed by some of its extinct relatives. The fossil shark teeth common in the phosphate beds of South Carolina and in other Tertiary and Pleistocene formations are sometimes six inches long and five wide, three times as large as in the largest white sharks, and the animal, if of proportionate size, must have attained a length of ninety feet, equaling or exceeding the largest whales. It is possible that sharks of this size still exist, altho they have never been reported on good authority, for teeth of similar dimensions have been obtained in deep-sea dredging. A restoration of the jaws of this gigantic extinct shark with the (original) teeth all in position has recently been placed on exhibition in the Natural History Museum in New York. The gape of the jaws is nearly seven feet, so that this monster could almost have swallowed a small vessel, crew and all, and the traditional Jonah could easily have walked down his throat if opened for the purpose.

Closely related to the white shark are the mackerel sharks, porbeagles and salmon-sharks, not attaining such giant size, but equally swift and voracious. The high triangular back-fin and the mackerel-like tail are characteristic features of this group. The basking shark is the largest of the family and the largest of all true fishes, attaining a length of thirty-six feet and an enormous bulk. Unlike its relatives, it is a dull, sluggish animal, and does not pursue large prey.

The blue sharks, tiger-sharks and cub or harbor sharks are much more common and familiar than the white shark and its allies, and almost equal it in swiftness and ferocity, and sometimes in gigantic size. The dorsal fin is not so high and triangular, and the lobes of the tail are very unequal, the upper lobe projecting far backward, while the lower lobe is small. The blue shark, so commonly seen following ships, and the cub-shark, common around the waters of tropical harbors, are usually credited with the dangerous ferocity of the white shark, which they hardly deserve.

The rays and skates are related to the true sharks, but have the body flattened out and the pectoral fins extended in a thin, continuous flap along the sides, so that the animal has the shape of a flounder or halibut. They are bottom feeders, living on shells and crustaceans, and harmless, except for the sting rays, which can deliver a severe wound by a slash of the spiny tail, and the torpedoes, which have an electric organ capable of giving a severe benumbing shock to an enemy. The sea-devils are gigantic rays, the great wing-like fins expanding twenty feet.

Most modern fishes have a bony internal skeleton, and in various respects are higher types than the sharks. There are various partly intermediate forms between sharks and true bony fishes, but their relationships need not be considered here.

The perch and bass are usually considered the most typical of this group, and from this type as a center they vary into an endless diversity of form structure and habit. Most of them are marine, but many inhabit fresh-water lakes, rivers and brooks. In the ocean they are abundant everywhere, from shore to far out at sea, from the surface to great depths. Nowhere are they so varied or brightly colored as around the coral roofs of tropical seas; but they are equally abundant in the colder waters of the northern waters. They form an important part of the food of all maritime peoples; the value of the herring fishery alone is over thirty-seven million dollars annually.

The most ancient type of true bony fish are the soft-finned fishes, allies of the herring and the trout. The herring, running in immense "schools" in all the northern seas, is more used for food than any other fish, and "its spawning and feeding grounds have determined the location of cities." Closely allied to the herring is the shad, highly prized as a food fish in the United States, and the menhaden, caught chiefly for its oil as a manure for fields. The much larger tarpon of the South Atlantic is a favorite game-fish, reaching a length of six feet or more and affording exciting sport to the angler. Extinct allies of the tarpon in the Cretaceous seas (Portheus) reached a length of twelve feet.

The trout and salmon live partly or wholly in fresh water, the salmon ascending rivers from the sea to spawn, while the trout live entirely in fresh water, running streams or lakes, and the whitefish inhabit the great fresh-water lakes of North America. The Pacific salmon enters the rivers only for spawning, takes no food during its desperate struggle up to the headwaters of the stream, and dies when the spawning is completed, the young returning to the sea at the next high water. The Atlantic and European salmon, much more closely related to the trout, spend a much larger part of their lives in fresh water, while on the other hand several species of trout descend for a time to the sea, and others live partly or wholly in fresh-water lakes and ponds. Salmon and trout are the chief of game fish. In beauty and variety of color, in delicacy of flavor, in fighting qualities and in wariness, they rank with any fish.

If the trout and salmon are the favorites of the fresh-water fisherman, eels are perhaps the most heartily disliked. Their long, snaky form, ugly color, slimy skin, and their unpleasant addiction to "swallowing the bait" would be causes enough, but in addition they are one of the worst enemies of the game fishes. The spawning of the fresh-water eel was long a mystery, only very recently solved. The truth is that they descend to the sea to spawn, reversing the habits of the salmon.

The carp family includes a great many fresh-water fish, mostly small and less active than the salmon group. Both carp and salmon families are found only in the northern temperate regions. The carp and chub, dace and roach, minnow and shiner, are familiar in our brooks and streams, none of them gamy, none very good eating, but passable in absence of better fish. The carp and the nearly related goldfish are natives of China, domesticated there for centuries and introduced into Europe about 300 years ago.

Another familiar group of fresh-water fishes is the cat-fish family. They derive their name from the barbels or feelers around the mouth, which suggest the "smellers" of a cat. They are not scaly, but often head and parts of body are armored with bony plates. Their especial home is in South America, but they are common also in the northern continents and a few in Africa. They are all carnivorous gamy fish, fair to good eating, and most of them are found in river channels or muddy streams. Similar in habits but more graceful in form are the pike and muskallonge, the first living in fresh-water streams of all the northern continents, the second in the Great Lakes.

In the south temperate zone, where there are no true trout, their place is taken by a distinct group of fishes of the same habits. They are the "trout" of New Zealand, Australia, Tasmania, Patagonia and the Falkland Islands, and of South Africa. It has been supposed that these fresh-water fish, living in the isolated continents of the south, and unknown in equatorial or northern regions, must have spread from one to another region by way of an antarctic continent now submerged. It has recently been found, however, that these fish are able to live in salt water as well as fresh, so that they may have been distributed by sea.

The largest and most typical of the great groups of bony fishes are the spiny-rayed fish, typified by the perch and mackerel. Numerous fresh-water and more abundant marine fish are included in this order; only a few of the best-known kinds can be mentioned here.

The mackerel of the North Atlantic runs in great schools, estimated to contain many millions of fish, varying a great deal from year to year in their course. It furnishes one of the principal fisheries of New England. Larger relatives of the mackerel are the tunny, albacore and bonito of the warmer seas, and the Spanish mackerel of the West Indies. All these are swift, graceful, handsome fishes. The mackerel are preyed upon by their larger relative, the swordfish, which follows the schools to the New England coasts. Its presence is a sign that there are mackerel about. It is one of the swiftest of fishes; the graceful, compact body, forked tail and pointed head with long, sword-like upper jaw are all peculiarly fitted for speed. The swordfish frequently attacks ships or boats, driving its sword through a heavy plank without difficulty.

The bluefish is another well-known predacious fish of the North Atlantic. It is said to be the most destructive of all fishes in the waters it inhabits, pursuing the schools of smaller fish and killing far more than it requires for food. Professor Baird has estimated that during their stay on the New England coast the bluefish destroy upward of twelve hundred million million of smaller fish.

The order of perch-like fish includes a great variety of familiar fishes, fresh-water and marine—the perch, bass, darters and sunfish of the still streams and lakes of the north temperate zone; the sea bass and their relatives which in Australia, South America and South Africa have invaded the rivers and take the place and name of perch; the bright-colored groups of tropical seas. The parrot-fish, damsel-fish and angel-fish of the coral reefs, the sculpins and gurnards are more or less nearly related. The flat fishes are a curious offshoot of the spiny-rayed fishes. The body is very deep and narrow, but the fish swims on its side, one eye being twisted around from its normal position so that both of the eyes are on the side which lies uppermost. This side is also darker colored than the under side. In some flatfish it is the right, in others the left side which lies uppermost and shows the eyes and darker coloration. The flounders, soles, halibut, turbot and plaice are the best known of the flatfish. All are excellent food fishes.

The codfish family—codfish, pollock, haddock and various smaller species—are more remotely related to the spiny finned fishes, and are of great importance as a food fish. For four centuries the Banks of Newfoundland have been the chief center of the cod fishery. Among the fishing vessels all nations are represented, and in succession have come the Basque, Dutch, English, American and Scandinavian fishermen.

CHAPTER VII

THE VERTEBRATES—II. AMPHIBIA AND REPTILES

The Frogs, Toads, Efts and Salamanders are intermediate between aquatic and terrestrial vertebrates, between fishes and reptiles. In early life they are tadpoles, living in water, breathing by gills, having no true limbs, but a fringe or fin like the median fins of many fishes. Later they undergo a metamorphosis, bud out true limbs with feet, lose their gills and develop lungs, and become adapted to life on land. They are to some extent intermediate between fishes and reptiles, but are in fact much closer to reptiles if we compare the adult animals. Altho fish-like in their early development, there is a wide gap between them and any true fishes, living or extinct.

There are two groups of amphibians, the frogs and toads, tailless; and the efts and salamanders with long, heavy tails. The efts or newts and salamanders look very like lizards, but may be distinguished by their broad, flat heads. They frequent damp woods and borders of ponds, and may often be found by overturning stones or logs in such places. Most of them are quite small, but the giant salamander of Japan ("Cryptobranchus") reaches a length of five feet, and the closely related hellbender is sometimes eighteen inches long. The smaller efts are common in all the northern continents, and a few are found in North Africa and along the Andes Mountains as far south as Argentina. Some of the tailed amphibians retain their gills throughout their life, especially if the conditions favor their continued aquatic life.

The toads and frogs are familiar to every one and are found in all parts of the world, except in some of the oceanic islands. Toads are harmless creatures, helpful to the gardener from the quantities of insects they consume, many of them curiously interesting in their mating and egg-laying habits, and it is hard to see why they should be regarded with such general aversion. Like most Amphibians, there is a poisonous secretion in the skin which protects them from the attacks of more active animals, but this is not exuded from the surface save in extremity, and they can be handled with perfect safety, the poison acting only internally. There is no ground for the notion that warts on the skin are the result of handling toads. A curious myth found in early books on natural history and embalmed by Shakespeare in a quotation familiar to all, credits the toad with bearing a "precious jewel in his head."

The frogs, less poisonous than toads, are protected by their greater activity and more amphibious habits. The tree-toads are protected by their genius at concealment, and altho every one has heard their loud trilling, it is surprising how few persons have seen the little green chap with sucker-like disks on the tips of the toes who is responsible for it.

The modern amphibians are diminutive and specialized descendants of what was once a numerous and important race. The Primitive Amphibians or Armored Amphibians of the Coal Period were the first of land vertebrates, and were the dominant type of land animals until the appearance of the reptiles. These Armored Amphibians were much like salamanders in appearance, but the top of the head was solidly roofed over by bone and the under side of the body covered with scaly armor. Some of them were gigantic as compared with their modern descendants, ten or twelve feet in length, with skulls two feet long and a foot and a half wide. From some of these ancient amphibians were probably descended the reptiles, birds and mammals of later geologic ages.

The class of reptiles includes several very diverse kinds of animals —the snakes, lizards, crocodiles and turtles. Superficially they have not much in common except for the scaly skin, and that they (mostly) lay eggs and (all) breathe by lungs throughout their lives. The construction of the skeleton and the various details of internal organization show that they are in fact related to each other, tho not very closely, and geologic history shows that they are the scattered and specialized survivors of a class of vertebrates which for countless centuries was the dominant type of land animal. The Age of Reptiles is estimated to have endured for some nine millions of years; the Age of Mammals, which followed it and culminated in the appearance of man, for three millions of years. Compared with these vast periods the duration of historic time shrinks into insignificance.

The reptiles evolved from the Primitive Amphibians of the Coal Period, and the earliest reptiles are with difficulty distinguished from them. But they were more progressive in adapting themselves to the active and varied life of the land, and developed a higher and more active organization. The most important and interesting of these ancient reptiles were the Dinosaurs, adapted to live on dry land, and taking the place in nature that was subsequently to be taken by land mammals, the ordinary quadrupeds of the present day. But in addition to these, there were reptiles adapted to flying and others which reinvaded the ocean and became adapted to swimming, altho still keeping their air-breathing habit.

The oldest reptiles, appearing at the latter end of the Coal Period, were clumsy, heavy-bodied beasts, with short, crooked legs like crocodiles or turtles, some of them carnivorous, others herbivorous. The most singular of these ancient reptiles were the Pelycosaurians, or Fin-backed Reptiles, with an enormous rigid bony fin on the back, the purpose of which, unless for ornament, is a standing puzzle to zoologists.

The Dinosaurs are perhaps most obviously distinguished as long-legged reptiles, for in all of them the legs are long and straight as in modern land quadrupeds, instead of short and crooked as in modern reptiles. They were the characteristic land animals during the whole of the Age of Reptiles, comprising the Triassic, Jurassic and Cretaceous Periods, and many of them reached a gigantic size, rivaling the largest of living animals. Besides these gigantic forms, there were numerous smaller, lighter, more agile kinds, many of them known only by their foot-prints preserved in the ancient tidal flats of the Connecticut Valley and elsewhere. And there is reason to believe that there were multitudes of small upland dinosaurs of which nothing is known, because they never frequented the river-bottoms, swamps and seashores where sediments were being deposited that they might preserve their remains to the present day. Only in their modified descendants, readapted to swamp or riverside life, can be perceived the traces remaining of what must have originally been an adaptation to upland life.

The hugest of the Dinosaurs were the Brontosaurus and Diplodocus, reaching a length of sixty to eighty feet and a mass of over thirty tons in weight. These were probably amphibious animals, adapted to wade in water from twenty to fifty feet in depth. They had a massive elephantine body, supported on four straight, rather long legs, with feet very like those of elephants, except for large, blunt claws, one on the fore-foot, three on the hind-foot, which may have served to anchor the foot in slippery mud. The neck was long and flexible, enabling the animal to wade to considerable depth while keeping his head above water; the tail long, heavy and massive as in most reptiles. The skin was not scaly, but naked, thick and heavy like that of a whale. The head is very small in proportion, the teeth adapted to tearing off soft water plants or other such material, but not to chew the food nor to attack other animals. The brain is extremely small, and was of low organization even for a reptile, the great mass of the nervous system being the nerves and ganglia of the spinal cord. From this it is seen that the animal was slow and unintelligent, the actions chiefly reflex, and the Brontosaurus may be regarded as little more than a huge automaton, a vast storehouse of animal matter, with but little intelligence, and its movements mostly directed by reflex action. Through its aquatic life, the water buoying up most of its enormous weight, it was able to attain a size comparable only with modern whales and sharks. But its movements must have been slow and clumsy, and on land it would be utterly helpless; it was protected from its chief enemies, the carnivorous dinosaurs, by being able to wade to a depth beyond their reach.

Skeletons or casts of skeletons of some of these gigantic amphibious dinosaurs have recently been mounted in several of the larger museums in America and Europe and are among the most impressive records of the past history of the world.

The carnivorous dinosaurs were very different in appearance and habits. They were biped reptiles, with long hind limbs and bird-like feet, small fore limbs, large, sharp claws, short neck and large head with sharp-pointed, saw-edged teeth, and a long, lizard-like tail. Tracks of this type of dinosaur are abundant on the Connecticut sandstones and show that they usually walked or ran on the hind-limbs, seldom touching either fore-limbs or tail. These dinosaurs lived throughout the Age of Reptiles, both small, agile species and large, powerful ones. The most gigantic was the Tyrannosaurus of the late Cretaceous, forty feet in length, with a skull five feet long and teeth projecting four to six inches from their sockets. This animal must have nearly equaled an elephant in bulk and was adapted to prey upon the huge armored dinosaurs.

Other types of huge dinosaurs discovered in recent years are the armored Stegosaurs, covered with bony plates and spines, the great horned Ceratopsians with enormous skulls defended by long, sharp horns, and the duck-billed Trachodon and Iguanodon, unarmored, and with broad, horny, duck-like bill. These animals were all herbivorous, and except the Stegosaurs, had a fairly effective battery of grinding teeth. They reached a length of twenty to thirty feet and a bulk comparable to a hippopotamus or an elephant. They also had numerous smaller relatives, more agile and apparently more upland in their habit, since their skeletons are rarely found complete in the ancient sediments of the river valleys and marshes of the Age of Reptiles. Mostly they are known to science only by the scattered bones and fragments brought down by the rivers from higher levels.

The Flying Reptiles, or "Pterodactyls," were contemporaries of the Dinosaurs and equally remarkable, altho less gigantic in size. These "dragons of the prime" had the fore limbs converted into bat-like wings by the extension of the little finger into a long, slender-jointed rod supporting a membrane wing like that of bats. The tail is rudimentary or converted into a long steering blade, and the skeleton throughout is very light and fragile, the bones being hollow and pneumatic (filled with air) as they are in birds. Most of the Pterodactyls were small, from six inches to three feet expanse of wing, but in the late Cretaceous appeared large forms (Pteranodon), some twenty feet from tip to tip of the wings, with large, straight, toothless beaks, adapted apparently to spearing fish. The Pteranodon skeletons are found in marine formations deposited far out at sea, while the small Pterodactyls, with shorter wings, lived near the land. All of them were apparently adapted for soaring rather than fluttering, and they may be regarded as nature's nearest approach to a modern aeroplane.

In the rivers and swamps of the Age of Reptiles might be found crocodiles and turtles not very unlike those of the present day, and a variety of extinct reptiles more or less resembling them. In the seas lived several kinds of marine reptiles, some of gigantic size. These, like the cetaceans, seals and sirenians of the present day, were derived from terrestrial ancestors, but had re-invaded the sea, where they competed to advantage with the finny autochthones by reason of their superior organization and air-breathing habit.

The Plesiosaurs were long-necked, with compact bodies and long, turtle-like flippers. The Ichthyosaurs were very fish-like in outward appearance, with short necks, long, slender jaws and shark-like tail, and were evidently adapted to swift swimming like the mackerel-shark or the dolphin. The Mosasaurs were more nearly related to the lizards, but with flipper-like feet, large heads, with powerful jaws and sharp, stout teeth and long, compressed tails. Some of the Mososaurs and Plesiosaurs reached a length of forty feet; the Ichthyosaurs were somewhat smaller. All these great marine reptiles had become extinct by the end of the Cretaceous Period, and their place in the world was taken by marine mammals, ancestors of the Cetaceans of our modern seas.

The world must have appeared strange from a modern viewpoint during the Age of Reptiles. The imagination must picture dry lands and swamps populated by long-legged reptiles, many of them fantastic and bizarre in appearance and all utterly unlike any living animals. The vegetation would be less strange, but its tropical aspect and the absence of many of the more abundant higher types of plants could hardly fail to impress the observer.

In place of birds were the Pterodactyls, soaring through the air or hanging bat-like from trees or projecting rocks. Along the seashore we might find many familiar invertebrates, corals, starfish, sea urchins, crustaceans and mollusks, and with them swarms of nautilus-like ammonites and squid-like belemnites. Along the shores and far out at sea, besides the numerous types of fishes more or less like those of the present day, would be found numbers of the huge voracious marine reptiles, Plesiosaurs and Ichthyosaurs and (in the Cretaceous Period) Mososaurs, rulers of the deep, as the Cetaceans are to-day.

The keynote of the Age of Reptiles, as compared with the world of to-day, was the dominance of brute force. The varied types of reptilia which ruled land and swamp, sea and air were but little inferior in size and not greatly inferior in mechanical organization, in strength and speed to the higher animals which have taken their place. But they were notably inferior in type of brain, with the intelligence, adaptability and agility which it entails. Their disappearance at the end of the Cretaceous Period is to be ascribed partly to their being unable to adapt themselves to changed conditions of life brought about by changes in climate and geography of the world which they inhabited, partly to the competition of the more intelligent and adaptable mammals and birds that were being evolved to compete with them. There may have been other important factors in causing their extinction; several have been suggested, many more might be suggested. But these are known causes and must have played an important part in the process; and others are mostly guesswork.

At the end of the Age of Reptiles there were a few surviving groups which have persisted to the present day with but little change. They were the turtles, crocodiles, lizards and snakes, which on account of their habits and environment came less directly into competition with the higher quadrupeds and birds or whose surroundings were not altered by changes in geography and climate. These are the reptiles of to-day, a small and despised remnant of a class which ruled the world for millions of years, and for gigantic and formidable beasts has hardly since been equaled.

The Turtles and Tortoises, "Chelonia," form a well-armored group. The slow-moving tortoise is one of the most thoroly protected of four-footed animals. Give him a chance to withdraw his head, legs and tail within his shell and close the lids, and no enemy can molest him unless it be large and powerful enough to crush his whole shell between its jaws. He lives upon snails, slugs, caterpillars, earthworms, etc., with a considerable addition of vegetable food, usually hibernates in winter, and continues his leisurely, untroubled existence for a long period of years, perhaps even for centuries. It is only in his younger days that he has much to fear from enemies. But the eggs and young are toothsome morsels for carnivorous animals, and in spite of the care with which the mother conceals her eggs in the sand, burying them and effacing all marks which might serve as guide to their location, probably very few survive to be adult.

Land tortoises are found everywhere except in the Australian region and are found on several isolated oceanic islands, where, unmolested by higher quadrupeds, they are very abundant and reach large size. Their aquatic relatives, to which the name "turtle" is usually restricted, are of several different groups similar in general appearance, but not very closely related. They are generally more active, less completely protected by shell, and with the feet more or less completely converted into flippers for swimming.

The pond-tortoises, or marsh-turtles (Terrapins) are nearest to the true land tortoises, but have a flatter shell. One of the prettiest among them is the Painted Terrapin (Chrysemys), with its handsome pattern of red and yellow on a background of dull greenish black, but most of them are dull colored. The Diamond-back Terrapin, noted as the finest of all edible turtles, frequents the salt marshes of the Atlantic coast, especially in the Southern States, but is rapidly becoming scarce except where artificially protected. The snapping turtles and mud turtles are more aquatic and less completely protected by bony shell. The sea turtles are wholly marine, mostly confined to tropical seas and valued not only as food but for the tortoise shell manufactured from the outer layer of the carapace. The largest of these marine turtles is the green turtle (Chelone), inevitably connected, in song and story, with aldermanic banquets and other such civic functions. A near relative is the hawksbill turtle, the chief source of the tortoise shell of commerce.

The Side-necked Turtles, abundant in the rivers of all the southern continents, are rather distantly related to those we have mentioned. Altho much alike superficially, the construction of the carapace is different, and in withdrawing the head into the shell they bend the neck sideways, while the others bend it vertically in an S-shaped curve. Vast numbers of these turtles live in the South American rivers.

The soft-shelled river turtles (Trionyx) of the northern continents on the one hand, and the marine leathery turtles on the other, are ancient offshoots of the main chelonian stock which have endured with little change since the Reptilian Age.

Like the turtles, the crocodiles are a race of ancient lineage. During the Age of Reptiles they infested both seas and rivers in all parts of the world. Since then their range has been gradually restricted. The marine forms long ago became extinct; the river crocodiles have disappeared from most temperate regions and are common only in tropical or subtropical rivers. The living species are grouped as alligators, crocodiles and gavials, differing in the width of the skull and to some extent in their food habits. The narrow-snouted gavials of the East Indies feed chiefly upon fish; the broad-headed alligators (chiefly new-world) and the crocodiles (chiefly old-world), with heads of medium width and muzzles notched at the sides near the front to receive a large tooth in the lower jaw, lie in wait for land animals which come down to the rivers to drink or attempt to cross. These also live partly on fish. They are said to dig burrows in the banks of the rivers where they dwell, and like turtles they lay their eggs in a nest in the dry sand or earth of the river bank, usually covering them up and leaving them to hatch by the heat of the sun.

The crocodile, with its covering of armor scales, its powerful jaws and tail, is still formidable in modern tropical rivers, and to primitive man, armed only with spears and arrows, it must have been almost unassailable. One cannot wonder at the superstitious respect in which it was held in ancient Egypt. The caimans of South America are closely related to the alligators.

In contrast with the slow-moving armored turtles and crocodiles the lizards are mostly quick, active, small in size and unprotected by armor, the skin covered with small horny scales. They are wholly terrestrial, most abundant in arid or desert regions, but they live almost everywhere except in the cold temperate and arctic zones. Their small size, quick movements, dexterity in hiding, and ability to live in rocky and desert places, enable them to compete very well with small mammals, and they are a numerous and varied race. For the most part they live upon insects and are very adept in catching them. A few lizards attain a considerable size. The monitors of Africa, the East Indies and Australia reach a length of six or seven feet; in the tropical parts of the New World the Iguanas attain an equal size.

Among the smaller kinds, the geckos, skinks and true lizards are most familiar. Professor Gadow describes the habits of the Gecko as follows: "In their native haunts they are very regular in their habits. Favorite resorts of theirs are old olive trees or oak trees, the rough and cracked bark of which affords excellent places for hiding in. Hollow trees are of course preferred. Not a single specimen is seen during the early hours of the morning or in the forenoon, but when the sun has become broiling hot and our own shadow passes over the stem of a tree we become aware of flitting little shadows which jerk over its surface. These are Geckos which had been basking, motionless, very dark gray, almost blackish, just like the color of the gray bark upon which the last season's wet moss has been scorched to a black cinder. It is difficult to espy a Gecko while it is glued on to such a tree. Only the little beady eyes betray it, watching you carefully. Nothing appears more easy than to catch that motionless thing. You put out your hand and it is gone; like a flash it has moved a foot higher up or down, to the right or to the left, just where you least expected it to go, and there it clings motionless as before. It does not seem to run; it glides along, dodging to the other side of the stem and back again. There is system in its motions, since, taking a last leisurely look around, it gently disappears in a rent or hole. Toward the evening, or when the shadows become longer, the Geckos become lively. One after another appears on the surface, upon the tree or at the entrance of the cave, and they all move about in their peculiar rushing jerks. Spiders, flies, mosquitoes, moths form the principal diet, and the hunting goes on well into the night. Where a gecko has been seen once it is sure to reappear the next day at the same hour. Those which take up their abode inside a house become almost domesticated. They are strange sights when hunting for flies, running up and down the papered walls; but we fairly gasp when they come to the upper corner, calmly bend over and with the next jerk slide along the whitewashed ceiling. We are accustomed to flies performing such feats, but at animals five inches long, supple and fat, we are inclined to draw the line. However, that is the way of Geckos, and—be it confessed—the more we ponder over the mechanism of their fingers and toes, the less we comprehend how such little vacua can support or suspend such heavy creatures from a dry and often porous surface."

Among the fifteen hundred species of true lizards many are of very odd appearance and interesting habits. The "flying dragons" of the East Indies have wing-like membranes shaped very like the wings of a butterfly when extended, supported by long extensions of the ribs, and used as parachutes in long leaps from tree to tree. They are not much larger than a large butterfly, so that the name "dragon" is rather a misfit as to size. Another remarkable type is the Chlamydosaurus, or Frilled Lizard, of Australia, with very long, slender legs and tail and a large frill around the neck, which it erects when brought to bay. It runs ordinarily on its hind legs, the fore legs hanging down, the long tail balancing the body. In shape the frill has an absurd resemblance to the great bony neck frills of the Horned Dinosaurs, and the long legs and biped gait are also singularly like certain Dinosaurs. It is said to reach a length of two or three feet. The quaint little "Horned Toads" (Phrynosoma) of the Western United States, too, suggest some of the extinct Armored Dinosaurs. The ugly, poisonous Gila Monsters of the same region, brightly colored in orange and black, are a well-known example of warning coloration, the colors enabling the hungry bird or coyote to recognize and avoid them.

The Chameleons are found chiefly in Africa, altho they range into Spain and India as well. They are very odd and interesting little lizards in their habits, and their color changes have been carefully watched and studied. The head is high and narrow, the body compressed sideways, unlike most lizards, and the feet are very peculiar, two toes in each foot being opposed to the other three. The tongue is very peculiarly constructed and the club-shaped sticky tip can be shot out suddenly to a distance of seven or eight inches, annexing the insect which the chameleon is stalking. They are extremely slow and cautious in their movements. The changes in color are only partly protective, chiefly related to the excitement or quiescence of the animal, or to heat and cold, as was long ago stated by Linnæus. Some of the Madagascar chameleons reach a length of two feet, but they are mostly only a few inches long.

No reptiles are so familiar, and yet so much maligned, as snakes. Most people regard a snake with horror, or at least with strong aversion. It is nasty, slimy, venomous; it kills chickens, it "fascinates" and devours little song-birds, and its bite is deadly poison to man. It is a thing to be killed on sight, but from a good distance and with stones or sticks, lest it attack you. Almost every small boy and the great majority of grown folk will kill any snake they see, feeling that is the natural and proper thing to do.

As a matter of fact, snakes are not at all slimy. Their skin is perfectly dry and scaly; they are quite as clean to handle as any dog or cat. There are a few poisonous snakes, but one may readily learn to recognize and avoid them. Most snakes (except in Australia) are perfectly harmless, and are a great help to the farmer, as they devour quantities of mice and insects. Snakes do not fascinate birds—the fluttering, apparently helpless bird is simply trying its best to entice the snake away from its nest.

No snake, poisonous or non-poisonous, will pursue a human being; their chief anxiety, if they see one, is to get away as quickly as they can to a place of safety. When cornered or suddenly disturbed without a chance to escape they will hiss and strike with the fore part of the body—a snake's striking distance is from a third to a half its length—but all this demonstration is entirely harmless unless the snake is a poisonous one and strikes some part of the body where its fangs can get through the clothing to the skin. For all the popular fear of snakes, actual recorded cases of death from the bite of a poisonous snake in the United States are extremely rare. In India and in other tropical countries the case is different. The mortality from snake-bite is large, partly because venomous serpents are more common, chiefly because the natives habitually travel barefoot through the jungle. The deaths from snake-bite in India are officially estimated at 22,000 a year—about one in fifteen thousand of the population. It is probably less in other tropical regions.

It is commonly said that poisonous snakes may be distinguished by their broad flat heads from the non-poisonous kinds. This is only partly true. The poisonous snakes of the viper family, including the viper, puff-adder, copperhead, water moccasin, fer-de-lance and rattlesnake, do have wide short heads; so do several kinds of non-poisonous snakes. But in the coral snakes and cobras, the deadliest of all venomous serpents, the head is of the same shape as the common harmless garter-snake or blacksnake.

Snakes are the most highly specialized of the reptilia. Altho undoubtedly descended from four-legged walking reptiles, no traces of the limbs remain except for some vestiges in the boa and python; the body is much elongated and adapted to crawling. The peculiar loosely hung double-jointed jaws and the very elastic throat and neck admit of extraordinary stretching so as to swallow the prey whole, so that the snake literally gets outside of his victim by alternately setting forward the upper and lower jaws with their sharp little recurved teeth. The poisonous snakes have one pair of teeth in the front of the jaw enlarged, and provided with a groove or canal through which the poison is injected into the wound. In the cobras and coral snakes the poison fangs are fixed; in the vipers they lie back against the roof of the mouth in repose, and are erected only when the snake opens its mouth to strike. The great majority of the species live on dry land, hiding at night, and in cold countries hibernating through the winter in crevices among rocks, in burrows made by rodents, or any other convenient shelter. Many snakes live partly or wholly in fresh-water streams or ponds; a few are marine. Some species lay eggs; others bring forth their young alive.

The largest snakes are the boas and pythons of tropical countries, which are said to reach a length sometimes of thirty feet, and kill their prey by crushing it between their coils—whence the name constrictor. Nine-tenths of the living species of snakes belong to the harmless colubrine group, of which the pretty striped garter-snakes are the most familiar kind. The blacksnakes, bullsnakes and hog-nosed snakes are well known in North America; many others, under various names, take their place in other continents. Some of these colubrine snakes constrict their prey, others swallow it without the formality of previously killing it.

Related to the colubrine snakes are the cobras of the Old World and coral-snakes of the New, all tropical or sub-tropical, and the most deadly of poisonous serpents. The majority of Australian snakes belong to this venomous group, so that in Australia the popular fear and hatred of snakes is justified more than in other continents. The peculiar habit of cobras, when angered and ready to strike, of expanding the skin of the neck into a broad, brightly marked "hood," may be compared with the rattle of a rattlesnake, and is usually supposed to serve as a warning signal, serving notice upon approaching large animals that a poisonous snake is at hand, to be carefully avoided and not carelessly stepped upon or eaten. Some perfectly harmless snakes have the custom, when one comes close to them, of rattling the tip of the tail among the dry leaves in a way that makes a fair imitation of a "singing" rattlesnake. This quivering of the tail may be—probably is—simply from excitement; nevertheless, it may serve to scare off larger animals of inquisitive disposition, and so be useful to the snake.

The snakes of the viper family are all poisonous, and inhabit both temperate and tropical regions. They include the vipers and puff-adders of Europe, Asia and Africa, the moccasins, copperheads and rattlesnakes of North America, and the palm-vipers and fer-de-lance of Tropical America and the West Indies. All are very poisonous, altho not quite so deadly as the cobra group. The virulence of the poison differs with the size and condition of the snake, as well as with the species, and with the size and stamina of the animal or person bitten. The bite of the fer-de-lance has the reputation of being most generally fatal to man.

CHAPTER VIII

THE VERTEBRATES—III. BIRDS

Birds as a class are the most attractive of animals. In intelligence, in restless activity, in compact graceful form, in handsome colors and markings, in musical voices they equal or surpass any others. Altho egg-laying like the lower vertebrates, they give far more care and attention to the incubating of the eggs and the rearing of the young. Family life is well developed among them, whereas among the lower vertebrates can be found only some scarcely recognizable beginnings of it. It is easy to understand and appreciate the actions and sensations of a bird where those of an ant are strange and foreign to the mental attitude of the human. Birds, too, are peculiarly the friends of man in his relations to the world of nature. They are the great natural check upon the multiplication of his insect enemies. It has been said that if it were not for birds the world would be so overrun with insects that all crops would be destroyed, successful farming would be impossible, and in consequence civilized man could no longer maintain his existence. This assertion greatly overrates their importance to civilization, in regarding them as indispensable to its continued existence. For, besides the birds, there are other important natural checks upon the indefinite multiplication of noxious insects, aside from the artificial checks devised by man, or which would be devised if the need for them were sufficiently urgent. Yet the services rendered by birds to the farmer are truly of immense value, far outbalancing the occasional toll taken from his seed-corn or his chicken-yard, even by those birds which are most generally counted as his enemies.

"A bird," says Gadow, "may be known by its feathers"—for all birds have feathers and no other animal possesses them. In other ways they form the most compact and readily distinguishable of the four groups of land vertebrates. They are all surprisingly alike in construction of skeleton and in the anatomy of the soft parts. With all their wide diversity in size and form and habits of life, it is singularly difficult to distinguish the bones of the different groups. The reason for this would seem to be that successful flight, in an animal as large as a bird, involves a high degree of specialization and mechanical perfection of skeleton and muscles, and limits the variations that may occur within rather narrow lines. The wide diversity of form and structure that exists among the mammals is not here found. Yet birds are an equally ancient group and have had ample time to assume diversity of form in relation to their diversity of habits hardly less than that of terrestrial quadrupeds. On the other hand, they show much more variety and brilliancy of color.

The high degree of specialization of birds appears throughout their organization. The fore-limbs are modified to serve as wings, the neck is long, the tail short and rudimentary so far as the skeleton is concerned. The heart is four-chambered and the circulation rapid and strong. The body is kept constantly at a temperature of 100°, instead of being only slightly higher than the temperature of the surrounding medium, as it is in the "cold-blooded" vertebrates. The lungs are large, and respiration is further aided by air-sacs which expand from the bronchial tubes into parts of the body cavity and the hollow bones. The muscles, as in mammals, are more distinct and sharply defined than in the lower vertebrates. The brain is of much higher type than in reptiles, and is comparable to the mammalian brain. All in all, the birds represent a development of the vertebrate stock ranking with the mammals as the highest type of animals, inferior in certain phases of intelligence but superior perhaps in activity and perfection of mechanism.

The feathers of a bird serve two essential purposes. In the first place they are bad conductors of heat, and prevent the body-heat from escaping, just as does the hair of mammals. Thus the bird and mammal are enabled to maintain a high bodily temperature, impossible to the scaly or naked-skinned reptiles, amphibians and fish. The high bodily temperature and rapid circulation are essential to the higher development and more active life of bird and mammal. The second essential purpose of the feathers is to aid in flight. While flight can be accomplished, as it is in bats or insects and was in pterodactyls, without the aid of feathers, yet they furnish the most effective mechanism that nature has devised for perfect control of movement in the air with animals as large as birds.

The classification of birds is a most difficult problem. The older arrangements, according to habits and external characters, do not altogether agree with the natural relationships of different groups. It is nevertheless very convenient, and the division into perchers, waders, birds of prey, marine birds, ostriches, etc., altho known to be unnatural, is largely used in default of general agreement as to the natural relationships of the different groups.

It may be assumed that birds are derived from some early type of primitive reptile, nearly related to the Dinosaurs, in the early part of the Age of Reptiles. This hypothetical ancestor of the bird would be distinguished from the small upland Dinosaurs mainly by the fact that its scales had evolved into feathers, thereby enabling it to maintain a higher body-temperature and more active life. Its habits would be much like those of the Ostriches, but the tail long, vertebrated, lizard-like, with feathers on each side, and the jaws provided with teeth instead of a horny beak. The transformation of the fore-limbs into wings might result either from their being used as an aid to running on the ground or in making soaring leaps from tree to tree. The second explanation is generally regarded as most probable.

The oldest known fossil bird, the "Archæopteryx" of the Jurassic Period (middle part of the Age of Reptiles), appears to be in this transitional stage. It was about the size of a crow and had the toothed jaws and long vertebrated tail of a reptile, feathered like the shaft of an arrow. Its wings were short and small, and in the opinion of some authors at least could hardly have served for true flight, but might enable it to flutter from bough to bough.

The remains of a few birds of the Cretaceous Period have been found. The two best known are the "Hesperornis" and "Ichthyornis," both provided with teeth, but the tail is of the usual Bird type. "Hesperornis" was a marine diver, allied to the Loons and Grebes and fully as large, but more primitive in various details of the skeleton. "Ichthyornis" was a flying bird, allied to the gulls. These three genera, "Archæopteryx," "Hesperornis" and "Ichthyornis," are the most important fossil birds as regards the evidence they offer toward the problem of the course of evolution of the birds and the relations of the various modern orders. They are a long way, however, from clearing up the problem. Most of the remaining fossil birds are very imperfectly known, and a remarkably large proportion of the more familiar kinds are large, flightless ground birds. This does not mean, as might be thought, that ground birds were formerly more abundant than now, but rather that on account of their size and habits their bones are more likely to be preserved and noticed by collectors than those of the smaller fragile-boned flying birds.

All that can be concluded as to the early evolution of the class is that they were derived from long-legged bipedal reptiles probably inhabitating the upland regions of the great land mass of the northern continents; that they developed feathers from scales primarily for warmth, secondarily for flight; that they subsequently lost their tails, and later on their teeth; but that at a very early period in their evolution they had become differentiated into various habits—perching, running, diving, soaring. Since the center of dispersal of their early evolution was the upland regions of the north, it is reasonable to expect to find the highest and most typical birds in that general habitat. Remnants of primitive bird-races, archaic survivals, we should expect to find in the most remote southern regions, or among marine or diving birds, or especially among the flightless ground birds. To a certain extent these expectations are carried out. But the birds are a race of ancient development and their strong and sustained flight gives them great powers of distribution over distances and across barriers that impede or baffle the migration of terrestrial animals. The bird life, therefore, of southern continents and tropical islands is much less peculiar and archaic than the mammalian life. The very primitive races have long ago been swept out of existence by competition with more progressive invaders. The apparently primitive survivals, such as the ground birds which to-day inhabit Australia, South Africa and South America, and others which have become extinct; such as the Penguins of the Antarctic region, the Loons and Grebes of northern lakes, the Auks and other apparently primitive types—all these must be regarded not as true primitive survivals, but as cases of at least partial reversion, of readaptation to ancestral habits from various stocks of more progressive and typical flying birds, where the conditions of their environment favored the development of types of birds similar in habits to early ancestors of the bird class.

The Ostrich is distinguished from all other ground birds by having only two toes. It is native to the African continent, but has been introduced in other arid regions with success and is the largest of living birds. A full-grown male stands over eight feet high and can outrun a horse. The handsome tail feathers have long been used for ornament, and the value of the annual output in South Africa is estimated at five million dollars, mostly derived from the large ostrich farms where the birds are semi-domesticated. The Rhea of southern America, the Emus and Cassowaries of Australasia and the Kiwi of New Zealand are similar in habits to the Ostrich, but of smaller size and with toes of the normal bird type.

Among the extinct flightless birds the Moas, which inhabited New Zealand in quite recent geologic times, were related to the Kiwi, but reached a much larger size than the Ostrich, the largest being estimated at twelve feet in height. The extermination of these birds by the Maori natives dates not more than four centuries ago. Equally recent is the disappearance of the great Æpyornis of Madagascar, upon which, it is said, the Eastern legends of the "Roc" are founded. The Roc, as it is described in the Arabian Nights, is exaggerated and distorted into a flying bird of impossibly gigantic size; but it may have been founded upon the eggs of these great ground birds, some of which are still in existence and large enough to hold two gallons of liquid.

These great flightless birds are usually grouped into a sub-class, Ratitæ, altho they are very probably degenerate descendants of several stocks of flying birds. There are other large extinct flightless birds in which the relationship to different groups of flying birds is more clearly seen. Such are the "Dodo" and "Solitaire" of Mauritius, related to the Pigeon, and exterminated only two centuries ago; the

"Phororhachos" of the Miocene epoch in Patagonia, related to the modern Seriema or Crested Screamer; the "Gastornis" of the European Eocene, related to the Ducks.

The most primitive—or degenerate—of marine birds are the Penguins of the Antarctic regions, flightless, active swimmers and divers, with the wings modified into paddles. In Penguins the three metatarsal bones of the hind foot are partially separate, more primitive than in any other bird. They are known to have inhabited the Antarctic seas at least as far back as the early Tertiary, and are probably a very ancient group. If future explorations should succeed in discovering fossil remains of the fauna which inhabited the old Antarctic continent during the Age of Mammals, it is very probable, in the present writer's opinion, that its higher land vertebrates will prove to have been, not mammals, but great ground birds of which the modern Penguins are a solitary marine survival.

The Divers and Grebes are the most primitive of the modern flying birds. Aquatic or marine in their habits, they are mostly heavy and awkward in flight or on land, but excellent swimmers and divers, using the webbed or lobed feet very effectively in swimming. The Divers are Arctic, the Grebes cosmopolitan in distribution.

The Petrels and Albatrosses and their allies are strong-flying ocean-birds, worldwide in distribution, but most abundant in the desolate wastes of the Southern oceans. Beyond all other birds they are at home on the ocean, resting and sleeping on the surface of the waves, resorting to land only for breeding purposes, and nesting on the rocky ledges of wild, inaccessible sea-cliffs.

A much larger group of water birds is represented by the Storks and their allies, mostly wading birds inhabiting fresh water, but some marine, like the tropic-birds, Gannets, Cormorants and Frigate-birds. The Storks, Ibises, Herons and Bitterns, the Flamingoes and Pelicans are the most familiar wading types, various in size and proportions, in habitat and nesting habits, feeding upon fish, frogs and other denizens of the marshes and rivers. Many of the birds of this group are distinguished by their large size, handsome colors and decorative plumes.

The Ducks and Geese are a still more familiar group of birds, aquatic in their habits, and mostly fresh-water dwellers, but swinming and diving rather than wading, more omnivorous in their feeding habits than the wading birds. They are cosmopolitan, but most abundant in the northern continents. The domesticated species are of large economic importance, and the wild species form a considerable proportion of the common game birds.

The Eagles, Hawks and Vultures are widely different in appearance and habits from the preceding groups. They constitute the "Birds of Prey," excluding the Owls, and are all carnivorous, mostly predacious, living on land, and preying upon smaller birds and mammals, or upon carrion, sometimes upon fish, occasionally upon insects. In accordance with their habits they are swift and powerful in their flight, the bill is adapted to seize and tear their prey, the claws are sharp, strong, and curved. The Condor of the Andes is one of the largest of flying birds. While to some extent Eagles and Hawks merit the hostility of man by their slaughter of smaller birds, their depredations upon the poultry-yard and their occasional attacks upon larger domestic animals, yet most of the hawks, at least, prey largely or chiefly upon rodents and, with the owls, are an important natural check upon their increase. As a class they undoubtedly do far more good than harm to the farmer, and their persecution is often followed by a terrifying increase in the numbers of noxious rodents.

The Domestic Fowl and their allies are the most familiar of birds and the most important economically. To this order belong, besides the domestic fowl, peacock, turkeys and guinea-fowl, the pheasants, partridges, grouse and quail, the curassows and hoatzin of South America and many less known birds. In the pheasant group are included the greater number of game-birds. The birds of this order are generally polygamous and the majority handsomely colored, especially the males.

The Rails, Cranes and Bustards are a second wading group, similar in habits to the storks and their allies, but not closely related. Another order of very varied habits is formed by the plovers, sandpipers and curlews, the gulls and auks and the pigeons, very diverse in outward form, but connected by common characters in the skeleton.

The Cuckoos and the Parrot family, comprising the Parrots, Parrakeets, Macaws and Cockatoos, are distinguished by having two of the toes reversed, instead of one as in most other birds, an especial adaptation for climbing and grasping branches.

A much larger order includes the Night-jars, swifts and humming-birds, the Owls, Kingfishers and woodpeckers, the trogons, toucans, hornbills and various other more or less familiar birds. They are all land-birds, of arboreal habits, with short legs, the majority nesting in holes in trees or similar places, and the young hatch out blind and peculiarly helpless. Their feeding habits are various, the owls being predacious, pursuing small mammals and birds and mostly nocturnal; the kingfishers feed upon fish, the woodpeckers especially upon boring beetles, the swifts and night-jars upon insects, the humming-birds upon the nectar of flowers, while the large toucans and hornbills are mainly fruit-eaters. The owls by their destruction of noxious rodents render aid to the farmer that far more than counterbalances the toll they levy on his chickens.

By far the largest order of birds is the Passeriformes, including the song-birds and their allies. It contains some 5,500 species, more than half the whole class. To this great order belong all the true singing birds, besides many which do not sing. They are mostly of small size, of high intelligence, as shown in their habits, their nest-building and in the care of their young. They are all land birds, terrestrial or arboreal in their nest-building, the feet adapted for perching, with one reversed digit and three in normal position; their powers of flight moderate or highly developed. A large proportion of them are seasonal migrants, traveling thousands of miles in their annual flights. They inhabit every region of the world, continents and islands; they range from seacoast swamps to above the snow-line in the mountains—forest, plain and desert, all have their special types of song-birds, adapted in habits and plumage to the requirements of their surroundings. Their numbers and variety are immense, and even in large ornithological books their mere enumeration is lengthy and cumbersome.

CHAPTER IX

THE VERTEBRATES—IV. MAMMALS

The mammals form the highest and most important group of the vertebrata. Broadly speaking, they correspond to the popular term of "quadruped," but also include man himself, and the whales, seals, and manatees. As reptiles have scales, and birds feathers, mammals have hair as their most obvious character. But the skin is often partly, rarely wholly, naked; and in a few mammals scales or bony plates are also present, covering the surface more or less completely. The young are born alive and suckled by the mother; this is the primary distinguishing character. They are warm-blooded, air-breathing, the heart with four chambers, and lungs and heart are separated from the abdominal organs by a muscular diaphragm.

The sense organs are more highly developed than in other vertebrates, the brain larger and more complex, the skull more consolidated. Teeth are nearly always present, and usually elaborated into various and often complex structures adapted to the various food requirements of the animal. The limbs and feet show an equally wide diversity in adaptation to various habits and modes of life.

The Tertiary Period is often called the Age of Mammals. During that time the mammals assumed the dominant position among animals, previously held by reptiles, and evolved, mostly from small ancestors of uniform type, into the diverse and often gigantic species of the present day. Ancestral mammals had first evolved from primitive reptiles long before, probably before the close of the Age of Amphibians, and these small primitive ancestors had been living side by side with the gigantic Dinosaurs during all the Age of Reptiles. They were rare and of minute size, probably tree-living animals, and it is not unlikely that their arboreal life, with its continual demands on intelligent action and readiness to grasp opportunities, stimulated the much higher grade of intelligence to which the mammals had attained when they first appear in numbers at the opening of the Tertiary Period.

These primitive ancestral mammals were small, long-tailed animals which might be compared to the modern tree-shrews. They had flexible limbs and feet, slender body, moderately long neck, slender skull, and long jaws with teeth adapted to insect-eating. The number of teeth was forty-four in all. The toes were five on each foot, the digits flexible, clawed, the inner digit to some extent opposable, and with one less joint than the others.

Fossil mammals have been found in great numbers and variety in the formations of successive epochs of the Tertiary Period, and it is possible to trace the successive stages through which they evolved from these small primitive types into the various kinds of modern quadrupeds. Conversely, when the ancestral series of any modern quadruped is traced back it is found leading down in every case toward this identical small primitive type; and when one examines and compares the structure and anatomy of any modern animal it is seen that it is most easily explained as a modification from this common primitive type in adaptation to one or another habit of life.

Some races have become herbivorous, others carnivorous, others fruit-eating, and the teeth have been modified in accordance. Some have remained arboreal, others have become terrestrial, aquatic, or fossorial; some have remained small, others have become large, or even gigantic in size; and the limbs and feet have been modified to suit their various habits and size.

In herbivorous mammals the cheek teeth are used for crushing and grinding vegetable food, the front teeth for cropping. The true molars are enlarged, and complicated into a more or less elaborate pattern of crests or crescentic ridges which serve to chop or grind the food. The premolars either degenerate or become like the molars. The canines are sometimes enlarged into tusks for fighting, sometimes degenerate and disappear. The incisors are converted into spadelike teeth for nipping off food, into large gnawing teeth, or degenerate and disappear. In carnivorous animals, on the other hand, the pointed canines, used for seizing and holding the prey, are large, sharp and strong; the premolars, used for cutting the food, are well developed; while the molars, used for grinding, tend to degenerate or disappear, or to become more like the premolars, and to be used chiefly for cutting up the food. In frugivorous animals the cheek teeth are used for crushing fruit or nuts, and become flat-topped; the premolars often degenerate; the front teeth, used for biting off the food, are converted into a row of little spade-shaped teeth. Animals of more mixed diet show various combinations of these characters in the dentition.

The animals which have remained arboreal have retained and perfected the adaptation of limbs and feet to this purpose, but have departed less than any others from the primitive type. Among terrestrial mammals are found a variety of adaptations. Some have developed speed, to escape from their enemies or pursue their prey. For this purpose they have taken to walking or running upon the fingers, or even upon the tips of the claws, instead of, as at first, upon the flat of the foot. In consequence, the lower limbs and feet are lengthened, the joints of the feet made stronger and more compact, the side toes tend to degenerate and the middle toes bear the weight of the body, and the claws are converted into broad, strong hoofs which finally support the whole weight. Other terrestrial races have depended upon their fighting capacity rather than upon speed; they have increased rapidly in size, developed horns, tusks, armor plates or spines, for attack or defense, and the limbs have become adapted to bearing enormous weights, with heavy bones, massive muscles, short, heavily padded feet. Fossorial mammals have developed short and exceedingly powerful limbs and great digging claws upon the feet. In aquatic mammals the feet become webbed, and are finally converted into paddles; or in such as developed a powerful swimming tail the hind limbs have degenerated and disappeared. Finally one group of aerial mammals appears, the bats, in which the fore limbs are converted into wings, by lengthening the fingers and developing a web between them and the sides of body and tail. Various arboreal mammals also have weblike expansions of the skin, which they stretch as parachutes in leaping from bough to bough.

The quadrupeds are less dependent upon temperature and climate than most of the lower animals, while they are more strictly limited in their migrations by the boundaries of the continents and islands which they inhabit. Moreover, they are not so ancient as the invertebrates and lower vertebrates; their evolution and dispersal over the world has mostly occurred during the Tertiary Period, when the distribution of land and water was not so very different from what it is at present. We find that the present general arrangement of the land areas, with a great central northern land mass and isolated peninsular continents stretching down into the southern hemisphere, is the key to the geographical distribution of mammals. They have spread out in successive waves of migration from one part or another of the Holarctic region, and each new wave of higher stages of evolution in the different races has driven its more primitive predecessors before it toward the remotest confines of the southern continents and islands. This general tendency has been limited by the land connections with the southern continents and islands.

The connection with South America was interrupted during a part of the Tertiary, and during that interruption the South American animals evolved independently into races which were quite different from those of the northern world. When connection was resumed, the northern animals invaded South America, while some of the southern races invaded North America; but the superior quality of the animals evolved on the great northern land mass enabled them to overcome and displace those of South American origin, which have nearly all become extinct. In Africa and in peninsular India the connection was also interrupted for a time and then restored, with the same results; but the interruption did not last so long. Australia and the adjoining islands have been separated since before the Tertiary Period, and the higher mammals have never been able to reach those regions. In consequence, the more primitive mammals which reached there at an earlier period have evolved and specialized into a large and varied mammal fauna paralleling the higher mammals of the northern world.

Some of the East Indian islands, now separated from the mainland only by shallow seas, have been united with it during the Tertiary Period, so that the great land animals could invade and occupy them. Other oceanic islands, like Celebes, Madagascar, the West Indies, New Zealand, and many smaller islands, are separated by deep oceans from the mainland. In these it is noted that land mammals are generally absent, or are peculiar types different from those of other regions, and probably developed on the island themselves from such small mammals as might once in a long while reach their shores on floating rafts drifted out from the mouths of rivers on the mainland. Small mammals, such as rodents, insectivores, or small lemurs, might once in a while gain a footing on the isolated island in this way, and once established, in the absence of competition would evolve into a variety of larger races, as the Marsupials did in Australia. In this way can be explained why Madagascar possessses none of the elephants, rhinoceroses, zebras, antelopes, dogs, cats, etc., of the adjoining coast of Africa, but does have a great number of lemurs not found elsewhere, a number of insectivores of a family (Centetidæ) peculiar to the island, two or three carnivores, related to the civets but of very exceptional character. The bush-pigs may have been brought there by man; the pigmy hippopotami found fossil on the island may have reached it by swimming. But the absence of practically all the mainland animals, together with the presence of peculiar types which seem adapted to take their place, can scarcely be explained except by supposing that the land has been separated from the African mainland for a very long period. The problems of geographical distribution are a most fascinating branch of zoology and have attracted a large share of the attention of scientific men, especially in recent years.

In the arrangement of this class of vertebrates first must be set aside the Egg-laying mammals of Australia as an exceedingly archaic type, to a great extent a connecting link between mammals and the primitive reptiles from which they are descended. As might be expected, these most ancient of mammals are found on the very outskirts of the mammalian domain, Southern Australia and Tasmania, most remote from the main center of Mammalian evolution in the north. These form the sub-class Prototheria.

The rest of the mammals may be divided again into a small and a large group, the Marsupials, or Pouched Mammals (Metatheria), in which the young are born alive, but very immature, and are carried for some time in a pouch on the under side of the mother's body until they are able to shift for themselves; and the Placental Mammals, "Eutheria," including all the rest. In the placentals the young are more mature when born, and are never carried about in a pouch. Either they are able to follow the mother about, or she remains with them, in some suitably protected spot, until they are well grown.

There are, of course, numerous distinctions in the skeleton and soft anatomy to support this division of the mammals into Prototherians, Metatherians and Eutherians; but from a modern point of view it is well to lay weight on these differences in the care of the young. For, as has been seen among invertebrates, the progressively greater care of the young, the prolongation of infancy, appears to be, more than anything else, the key to the possibilities of higher development. Among insects it is patent that the higher life of the social wasps and bees centers mainly about the care of the young. It is no less true among vertebrates. The most prominent feature in the life of birds and mammals is the care that they take of their young; and in the higher orders of mammals the period of infancy becomes progressively longer until it reaches its maximum in man.

The Mammalia are further divisible into twenty-three orders as generally accepted in recent years. The arrangement is as follows:

I. Sub-Class Prototheria. Egg-laying Mammals.
    1. Order Monotremata, Ornithorhynchus and Echnida.
II. Sub-Class Metatheria. Pouched Mammals.
    2. Order Marsupialia. Opossums, Kangaroos, etc.
III. Sub-Class Eutheria. Placental Mammals.
    3. Order Insectivora. Hedgehogs, Moles, etc.
    4. Order Edentata. Sloths, Armadillos, etc.
    5. Order Cetacea. Whales, Dolphins, etc.
    6. Order Sirenia. Manatee and Dugong.
    7. Order Perissodactyla. Horses, Rhinoceroses, Tapirs.
    8. Order Artiodactyla. Pigs and Ruminants.
    9. Order Proboscidea. Elephants.
    10-16. Orders Condylarthra, Amblypoda, Toxodontia, Astoptema, Arsinoitheria, Embrithopoda, Astrapotheria. Extinct Hoofed Mammals.
    17. Order Hyracoidea. Conies.
    18. Order Rodentia. Rats, Mice, Rabbits, etc.
    19-20. Orders Tillodonta and Tæniodonta. Extinct Clawed Mammals.
    21. Order Carnivora. Dogs, Cats, Weasels, Civets, etc.
    22. Order Chiroptera. Bats.
    23. Order Primates. Lemurs, Monkeys, Apes, Man.

The Egg-laying Mammals, therefore, must be treated first. These two little animals, the "Ornithorhynchus," or Duck-bill, and the "Echidna," or Spiny Anteater, inhabit Southern Australia and Tasmania. They are the most archaic of all mammals, and from their geographic location may be regarded as the vanguard of the great mammalian dispersion which has spread out in successive waves from the northern continental land masses. They are classed with mammals because of their hair-covered skin, solid skull, jaws all of one piece, and various features of their anatomy, but they retain numerous characters in the skeleton approaching those of the primitive reptiles of the Coal Period from which the mammals are believed to be descended. Like the Marsupials, these animals are provided with a pouch, to which the eggs are transferred after they are laid. The eggs are hatched in the pouch, and the young animal remains there for some time, nourished by a secretion from the skin of the mother.

The Ornithorhynchus lives in burrows along the margin of ponds and streams feeding upon fresh-water clams, crustaceans, etc. "During the Australian winter," says Doctor Semon, "from June till the end of August, when the nights are cold, you may be sure to find the animals in the river at sunrise and sunset. If you are near the river early enough to watch the rising of the sun, you will see something flat, one or two feet in length, floating on the water, like a plank, as soon as the first sunbeams strike the river surface and allow you to discern single objects. Sometimes it lies motionless for a while, then it disappears, to reappear again after a few moments in quite a different place. This is an Ornithorhynchus seeking its breakfast in the mire of the river."

The Echidna, or Spiny Anteater, is a shy, nocturnal, burrowing animal, living in the dense, impenetrable scrub and wild, rocky parts of the country. "On its nightly expeditions," says Semon again, "the anteater seeks worms and insects of all kinds, which it extracts from their hiding places in earth holes, between stones, and in rotting bark, by means of its long, wormlike tongue. Its principal food, however, consists of ants, which it captures like other anteaters, by thrusting its tongue into the anthill, waiting till it is covered with ants, and then drawing it in quickly.

It is interesting to note that the Pouched Mammals have a lower and less constant body temperature than any of the higher mammals. In this respect also they approach the reptiles and other "cold-blooded" vertebrates.

The Marsupials are more or less intermediate between the Monotremes and the placental mammals, but decidedly nearer in all respects to the latter. They lack a placenta, that particular internal organ which enables the young to be brought to a maturer, more perfected state before birth. In consequence they are born in a very rudimentary condition, and are usually transferred to a pouch on the under side of the mother to complete their development. Teats are present, as in the higher mammals, and the little animal is suckled within the pouch.

Marsupials are to-day chiefly found in Australia and the adjacent islands. The opossums of South and Central America, of which one species ranges northward into the United States, and a rare little animal (Cænolestes) recently discovered in the Andean highlands, are the only living representatives of the order outside of Australasia (except that a few of the Australian marsupials also range northward into the East Indies). Formerly the Marsupials were worldwide in their distribution. It is probable that most, if not all, of the tiny, shrew-like mammals which have been referred to as contemporaries of the gigantic Dinosaurs during the Age of Reptiles were Marsupials, or at least equivalent to them in their stage of evolution. But with the advent of the higher placental mammals at the beginning of the Tertiary Period, the Marsupials gradually disappeared from the northern world. A few survivors have been found among the early Tertiary mammals of Europe and North America, and they were abundant in South America until the latter part of the Tertiary Period, when a great invasion of the northern mammals swept them out of existence save for the opossums and "Cænolestes."

In Australia, however, they were undisturbed by northern competitors, as this continent remained isolated throughout the Tertiary Period. "They were allowed," says Semon, "to thrive unhindered, to regard the bush forests, the river banks, the rocks and mountains, the grassy pastures, as their undisputed domain, adapting themselves more and more to the characters of their surroundings. Some feed on the grass of the bush, like kangaroos and wallabies; others dig for roots and bulbs, like the kangaroo-rats; still others seek their food on eucalyptus trees, like Phascolarctus, the Australian opossum, and the flying Marsupials. Bandicoots (Peramelidæ) and the shrewlike bush rats and bush mice (Phascologale, Antechinomys) are mostly insectivorous; the native cat, the Tasmanian devil, and the pouched wolf carnivorous, with teeth strongly reminding us of those of Placentalia. As different as their food are the dwellings, the habits, and the modes of locomotion in all these animals. Like jumping mice, the kangaroos hop over the level country, some of them—for instance, the rock-wallabies—being able to execute their leaps also in mountainous country with the cleverness of a chamois, while the tree-kangaroo (Dendrolagus) performs real climbing antics in the crowns of the highest trees. We see the Australian opossum and the Cuscus climb with the agility of squirrels; Petaurus flits from tree to tree, and is therefore erroneously called by the Australians 'flying squirrel'; Phascolarctos, however, climbs along as lazily as any sloth. Slinking is the gait of the native cat, and trotting that of the pouched wolf.

"In the grass, in rocky caves, on the ground, or on trees, we find the hiding places and lairs of the marsupials. Like rabbits, the wombats dig long and deep burrows in the ground, and quite subterranean are the life and habits of the blind Notoryctes typhlops, which latter has but recently been discovered in the deepest interior of Australia, and the mien and habits of which strongly remind us of our mole; and still all these animals have nothing to do with moles, squirrels, flying-squirrels, rats, jumping-mice, shrew-mice, cats and wolves. All of them are marsupials, and related much more closely to each other than to any of the placental mammals which they resemble as to looks, movements or habits, and from which they derive their popular names. Further, we must not imagine that the placental beasts of prey have sprung from similar marsupial beasts of prey—the genuine jumping-mice from kangaroos, moles from Notoryctes, and so on. It is more probable that the transition from marsupials to placentals took place only once, and from a less specialized group of marsupials than now exists. The original group of placentals that arose thence has differentiated into distinct series, like insectivora, rodents, hoofed animals, beasts of prey, lemurs, apes and men. The outer resemblance between certain groups of marsupials and placentals is a phenomenon of convergence, and is produced by adaptation to similar conditions of life. It ought to be judged like the resemblance between wood lice and centipedes, fishes and whales, birds and bats. Outer resemblance is not always a proof of blood relationship. Echidna, porcupine and hedgehog are no wise related, much as they resemble each other, since the former is related to Ornithorhynchus, the second to the chinchilla, and the last to the mole."

The Marsupials are divided into two main groups. In the Polyprotodonts, mostly carnivorous or insectivorous, the canine teeth are sharp and strong, the incisor teeth small and set in a transverse row, and the cheek teeth adapted to cutting flesh or insect food. In the Diprotodonts, mostly herbivorous or frugivorous, the canine teeth are minute or absent, and one or two pairs of the incisor teeth are enlarged somewhat as in rodents, while the cheek teeth are fitted for crushing or chopping vegetation, fruit or nuts. In the first group the feet have usually five separate well-developed toes; in the second the toes are usually reduced in number, the fourth digit enlarged, the others enclosed in a common integument.

Of the Carnivorous Marsupials, or Polyprotodonts, the American opossums and the Thylacine, or Tasmanian "Wolf," the Tasmanian Devil (Sarcophilus) and Dasyure, or "Native Cat" of Australia, are the best known living types. In the Australian regions these take the place of true placental Carnivora of other continents, which are unknown there, except for the Dingo, or Wild Dog, probably introduced by man. But even in the short time that the dingo has been present on the main continent of Australia, his superiority as a hunter over his marsupial competitors is shown by the fact that the Thylacine and "Devil," abundant in Australia in prehistoric times, have disappeared from the mainland and survive only in Tasmania, where dingos have not been introduced. In South America during the Tertiary Period, while it was an island continent, there were, likewise, no true Carnivora, and there, too, the carnivorous marsupials developed into large wolf-like, lion-like and smaller cat-like or civet-like forms, to prey upon the various herbivora. When, toward the end of the Tertiary, the continent was united with North America, true carnivores invaded it from the north, and soon caused the extinction of all the carnivorous marsupials, except the opossums, whose arboreal habits and more omnivorous or insectivorous diet enabled them to survive to the present day. The fossil remains of these extinct South American marsupial carnivores discovered in recent years show so much resemblance to the Thylacines that they have been referred to the same family, and supposed to have migrated from Australia to South America by means of land connections with the Antarctic continent. In the present writer's opinion the resemblance is better explained as due to similar adaptation from primitive opossumlike marsupials, originally derived, with the rest of the South American and Australian mammals, from those primitive mammals which lived during the Age of Reptiles in the Northern continents.

These primitive marsupials, ancestors of the various living marsupials, and from which, at a somewhat earlier period, the remote ancestors of the higher, or placental, mammals had branched off, are pretty closely represented in the living opossums. So that one may, without very great straining of facts, place the 'possum in the gallery of ancestral portraits, and picture from him the sort of animal from which Man, in common with all the quadrupeds, is remotely descended. Little ratlike or shrewlike animals, with long, prehensile tail, with opposable thumb and great toe, insectivorous, living in trees, and venturing out from their hiding places mainly by night, alert and intelligent above their fellows of the Reptilian Era, but not by the higher standards of modern quadrupeds—such, as far as can be judged, were the remote ancestors of the mammals; and such are the opossums today.

The Thylacine is a much larger animal, with teeth specialized for flesh-eating and feet for running. It has superficial resemblance to a wolf; the striped rump suggests the tiger, also, while the long, stiff tail is an opossum character. It is now limited to the mountains of Tasmania, as is also the related "Tasmanian Devil," but both are found fossil in Australia. The Dasyures are smaller, civetlike animals of Australia and Tasmania which take the place of the smaller predacious carnivora of other parts of the world. The Bandicoots are small omnivorous or insectivorous marsupials, with teeth like those of the herbivorous group. In the Wombats the reverse is the case, the teeth being of the "diprotodont" type, while the feet have five well-developed toes with strong claws. These animals, in their heavy, clumsy build, short, stubby tail and shuffling walk, very much resemble small bears, and are commonly known as "native bears." The Phalangers are small squirrel-like marsupials, arboreal in their habits, and found throughout Australasia, ranging as far north and west as Amboyna and Celebes among the East Indian islands.

The largest living Marsupials are the Kangaroos, which in Australia take the place of the hoofed quadrupeds of other continents. "These animals," says Semon, "will always hold their own as the most characteristic feature of Australia. Every one who has observed them in zoological gardens and menageries will have remarked that there exist larger and smaller kinds of this animal, but we are apt to lose sight of the many and considerable differences between the various species and genera in the simple fact that the general quaintness of their aspect, the peculiar structure of their extremities and tail, and the queer manner of their locomotion, lead us to overlook everything else. Nevertheless, these animals, apparently so uniform in structure, show an astonishing variety in their more minute features, their habits and their distribution. If we reckon only the genuine Macropodidæ without the kangaroo-rats, we have to admit seven genera, comprising forty-three species; and of these twenty-three belong to the genus Macropus, the real kangaroo. The Australian colonists call all the larger kinds 'kangaroos' . . . the smaller kinds they call 'wallabies.'" The kangaroos "for the most part prefer the open bush, the level or undulating ground of which gives them occasion to exercise their splendid leaping powers, besides offering them a rich pasture. The leaps of the bigger kinds have generally a length of several yards. When chased they heighten the extent of a single leap to ten yards or more. The jerk is produced by the hind legs without assistance from the tail, as some think. This is easily proved by observing the track of the animals' leaps imprinted upon the ground. The tail is flourished at every leap, but hardly touches the earth. It seems to help the leaping animal to steer, and to support its weight when resting."

While the Kangaroos are the largest of living Marsupials, the extinct Diprotodon and Nototherium, which inhabited Australia during the Pleistocene Epoch, were gigantic animals, equaling the Indian Rhinoceros in bulk, and curiously resembling the modern elephant in the long, straight, massive postlike limbs and short, rounded, stubby feet. They were related to the Wombats, and may, in fact, be regarded as a sort of gigantic development of this race, adapted probably to a less arid climate and more abundant vegetation than now prevails in Australia. Numerous skeletons of these extinct giants have lately been found in the dried-up lakes of West Australia, north of Adelaide.

The Cetaceans are mammals which have become adapted to marine life and assumed a fishlike form, lost their hair, converted the fore limbs into paddles, lost the hind limbs entirely, and converted the tail into a swimming organ. They are only superficially like fish. The skeleton and internal organs, the quality of the muscles, the teeth, are all those of land mammals, and widely different from fish. They are warm-blooded, bring forth their young alive, and nurse them after the manner of land quadrupeds. The brain is far superior to that of any fish, and the intelligence is of a much higher order than that of fishes. The intelligence of the dolphin seems to have been noticed by men in prehistoric times, for it appears in Greek mythology as the friend and active helper of man.

The Cetaceans include the largest of known animals, living or extinct, the whalebone whales and sperm whales, and the numerous smaller active species of which the dolphins and porpoises are most familiar. The order is divided into two groups.

The Whalebone Whales (Mysticetæ) are toothless, and provided with fringed plates of whalebone which act as a sieve to catch and retain in the mouth the minute crustaceans, etc., upon which the animal feeds. There are several kinds of these whales, all of gigantic size. In the "Right" Whales, "Balæna," the head is more arched and the whalebone plates and fringes longer. In the Rorquals, "Balænoptera," the whalebone plates are smaller, and the animal is longer-bodied, the head less gigantic, there is a dorsal fin, or hump, not present on the right whales (whence the names of "finner" and "hump-back" applied to different species), and the throat has a series of longitudinal furrows. The species of Balæna reach a length of 40 to 70 feet, with an enormous bulk. The rorquals, tho somewhat less massive, attain even greater size. A large "sulphur bottom" whale will reach 75 to 85 feet in length and weigh about 75 tons. A skeleton in the Museum of Christchurch, New Zealand, is reported as measuring 87 feet in total length, the skull alone being 21 feet long. The danger and romance of whaling are departed, and it has become a merciless butchery, which bids fair soon to extinguish utterly the largest and most magnificent of living animals. The whalebone, which is now the only practical object of the pursuit, seems a pitifully inadequate compensation for their extinction.

The Toothed Cetaceans (Odontocetes) have no baleen plates, but the jaws are set with sharp-pointed recurved teeth, adapted to seize and hold the fish and other swift-swimming marine animals on which they prey. The sperm whale, or Cachalot, attain a size almost rivaling the Whalebone Whales; 55 to 60 feet is a conservative estimate of the length, and of this nearly a third is the gigantic, blunt-snouted head. In the cavities of the skull are stored vast quantities of fluid fat, the spermaceti of commerce. From the sperm whale is also obtained the rare and valuable substance ambergris, used in the preparation of perfumes.

Unlike the whalebone whales, which are confined to the cold temperate and Arctic seas, the sperm whale chiefly inhabits the tropical oceans. Its food is chiefly cuttlefish, and it is said to especially seek the gigantic octopus, which lives far beneath the surface of the deep seas, and has so rarely been seen by man that it was, till recently, regarded as a fabulous monster. Bullen, in the "Cruise of the Cachalot," has given a fascinating account of a combat between these giants of the deep. The spermaceti, oil and ambergris of the cachalot are the objects of a considerable fishery, which, however, does not at present threaten the extinction of the animal. The first two products are found in the other toothed cetaceans, but in smaller quantities.

The dolphins and porpoises, and their allies, are common in all parts of the world, mostly marine, but some of them inhabiting the great tropical rivers. The largest of the dolphin group is the grampus, or killer, a fierce predacious species which reaches a length of thirty feet. The Killer preys upon seals and porpoises, and several will combine to attack one of the larger whales. Another remarkable form is the Narwhal, in which the teeth are reduced to a single long, twisted tusk, projecting forward from the head to a length of six or seven feet. The purpose of this twisted tusk is not certainly known.

Among the numerous fossil cetaceans, the most interesting are the Zeuglodonts, a primitive group which serve to connect the cetacea with the land quadrupeds of the early Tertiary, especially with primitive carnivora or carnivorous insectivores. Altho marine, and fishlike in form, the teeth and skull characters approach more nearly to those of early carnivorous land mammals, from which they were, no doubt, derived. They have been found in the Eocene formations of Alabama, and, more recently, in Egypt.

Among the living relics of prehistoric animals preserved to this day in the isolated southern continents, the so-called Edentates are not the least interesting. The tree-sloths are sluggish, stupid creatures, covered with long, greenish-brown hair, which inhabit the Brazilian forests, hanging upside down from the trees by their long, curved claws, feeding upon leaves, and moving slowly and cautiously from bough to bough, and protected by their likeness in color and appearance to the mossy-green, lichen-covered branches around them. The armadillos are covered by bony plates embedded in the skin, forming a rigid buckler at each end of the body, with bands of movable plates between, so that the animal can roll up into an armor-covered ball.

They are fossorial animals, active diggers, and are found in all parts of South America, and as far north as southern Texas. The ant-eaters, also South American, are covered with long, shaggy hair, toothless, with long snouts and slender, protrusible tongue, and powerful claws to tear down the nests of the ants on which they are especially adapted to feed. These creatures are all of moderate size, the largest being the Great Anteater, seven feet in length, including the long, bushy tail. The term Edentates, or "toothless animals," applies strictly to the ant-eaters only; the others have teeth, altho they lack enamel. The living edentates are the remnants of a race which flourished greatly in South America during the Age of Mammals, while that region was an island continent, protected by ocean barriers from the incursions of the more highly developed mammals of the northern world. Some of the extinct edentates, the great Ground Sloths and Glyptodonts, attained gigantic size. The Megatherium almost rivaled an elephant in bulk, and was extraordinarily massive in skeleton; its allies, the Mylodons, were somewhat smaller. These huge animals were nearest to the tree sloths in structure, but were much too large to have lived in trees. They are supposed to have used their gigantic claws in digging up and uprooting trees upon whose foliage they fed. The Glyptodonts, or Tortoise-Armadillos, were covered with armor, a massive solid carapace, without the movable bands of the armadillo, and the feet hoofed instead of clawed. They had very efficient grinding teeth, and were presumably grazing animals. Some of them equaled a rhinoceros in bulk. Certain of these gigantic animals appear to have survived in Patagonia almost to historic time and to have been actually domesticated by the Indians of that region. The native legends tell of gigantic animals which correspond—not very accurately—with the Mylodon as it must have appeared in life; and in a cave at Last Hope Inlet, in Patagonia, there were recently found parts of the skin, well preserved and almost fresh, together with droppings of the Mylodon, and chopped grass, on which it is supposed to have been fed; the indications being that the animals were kept confined in a part of the cave.

The Order Insectivora includes the Hedgehogs, Moles, Shrews and many less familiar animals. The living Insectivores are the scattered remnants of an ancient race of mammals from whose earlier members were evolved the higher and more intelligent races which have mostly displaced them in the struggle for existence. The survivors are protected by spiny armor or nauseous taste or by burrowing habits, or else inhabit remote fringes of the continents or large islands, where they have escaped from the competition of higher types. All the insectivora are small or minute animals, with teeth adapted to a diet of insects, which form their principal food.

The best known of the insectivores are the hedgehogs, covered with a prickly coat, and, like the armadillos, able to roll themselves up into a ball which defies the assaults of any ordinary beast of prey; the moles, strictly subterranean, and almost blind, the fore limbs converted into very powerful and efficient digging instruments; and the shrews, less specialized for burrowing, but protected by their nocturnal habits and nauseaus taste. Few birds or animals will touch a shrew—the owl is almost the only one that preys upon it. Hedgehogs, moles and shrews inhabit the northern continents, hedgehogs being restricted to the Old World. Various other insectivores, more or less related to these, but mostly less specially protected, are found in South and West Africa, in the East and West Indies, and in Madagascar, and one species, at least, formerly existed in South America. In the early part of the Age of Mammals the Insectivores were far more numerous, and some of larger size, and they had not then developed the various extreme specializations by which the surviving members of the order have managed to prolong their existence. The higher mammals, in the opinion of Huxley, were probably derived from some of these very primitive unspecialized Insectivores.

The Bats, Order Chiroptera, are usually regarded as related to the Insectivores, but they are the most isolated and highly specialized of all mammals in relation to their habits of flight. In adaptation to this purpose the fore limbs, and especially the fingers, are greatly elongated, the hind limbs reduced and slender, twisted around so that the knee projects backward, and a thin, flexible wing membrane extends from the sides of the body to the tips of the fingers and from the front of the forearms to the hind limbs and usually to the tail. The pectoral muscles which move the wings are greatly enlarged, as they are in flying birds.

The thumb and the five toes of the hind foot are tipped with slender, curved claws by which the animal suspends himself when at rest, generally hanging upside down. Dr. W. L. Hahn, who has recently studied the habits of cave bats, observes: "They have no nests, dens or fixed homes. They have few enemies; consequently fear is little developed. About five-sixths of a bat's entire existence is spent in a dormant condition; a large amount of fat is favorable to torpor. In the caves, where conditions of light and temperature are constant, bats come to the cave entrance at irregular intervals. The length of time between these intervals depends upon the amount of surplus fat stored in the body.

"Food consists of insects that are caught on the wing. Hearing and the tactile sense are chiefly relied upon to perceive and locate food. Bats are more helpless on their feet than most birds. In the air they have greater agility. They can check their momentum very quickly. In flight they can secure hold of a surface only slightly rough with a single thumb or with one foot. Neither sight nor the external ears are necessary for the perception of obtacles during flight; such are perceived chiefly through the sense organs located in the internal ear; but the body hairs have probably a sensory function as well. Perception is probably due to the condensation of the atmosphere between the moving animal and the object which it is approaching. It is difficult to explain how they find their way by means of the five senses familiar to us. The presence of a sixth sense, that of direction, will explain all the facts, but it has not been conclusively shown that such a sense exists."

There are two principal groups of bats. The large Fruit-bats inhabit the East Indies, Africa and Madagascar, Australia and many of the Pacific islands, feeding upon fruit and hanging from branches of trees when not on the wing. The smaller insectivorous bats are much better known and are cosmopolitan in their distribution. The ears are large and complex, and many kinds possess peculiar leafy outgrowths from the nostrils which aid in perception of objects around, somewhat as do the antennæ of ants, save that it is the sense of touch that is elaborated, instead of that of smell. While most of them live on insects, a few are frugivorous or carnivorous, and the South American Desmodus, the true Vampire Bat, is a blood-sucker, fastening upon men or animals during sleep and inflicting severe wounds, with serious loss of blood, without awakening the sleeper, by means of its keen-edged front teeth.

The cave-haunting habits of modern bats are familiar, and their fossil remains have been found in ancient cave and crevice formations as far back as the early part of the Tertiary Period. All the extinct species are closely related to modern kinds and show nothing of the evolution of this singular group of mammals. They are probably of very ancient origin.

Next above the Insectivores in the scale of life may be placed the Rodents, including the Rats and Mice, Squirrels, Porcupines, Rabbits, etc. This group of mammals, altho comparatively low in scale of organization, is very abundant and varied, and highly successful in the battle of life. Their success may be ascribed to their great fecundity, their adaptability to changing conditions of life, and their readiness to combine together in social relations, not generally very complex, yet each serving to assist the others to a considerable extent. Whatever be the reasons, the rodents are by far the most numerous of the orders of mammals, both as to species and individuals. Nearly all are of small size. They are distributed all over the world, a few even reaching Australia, and are terrestrial, arboreal, fossorial or amphibious in their habits. None of them is marine and none is able to fly, although some have membranous expansions of the skin which can be stretched like parachutes in taking long, soaring leaps from tree to tree. The limbs and feet are mostly of primitive type, five-toed, tipped with claws, and the animal walks on the sole of the foot. The teeth are peculiar in the conversion of one pair of incisors in each jaw into gnawing teeth, and disappearance of all the other front teeth; the cheek teeth are adapted to crushing or grinding. Rodents live mainly upon seeds, roots, nuts, fruits, or upon grasses or the bark of trees; but they are by no means averse to insect or animal food.

More than half the living species of mammals belong to this order. It is divided into four groups, of which the squirrels, porcupines, rats and rabbits serve as types.

The squirrel group includes the squirrels, marmots, beavers, pocket-gophers, and their allies. The arboreal squirrels are the most intelligent and attractive of rodents, and are found all over the world, save in Australia and Madagascar. Their long, bushy tails, neat, smooth fur, and often handsome coloring, and their restless activity and chatter, offset their occasional depredations on birds' nests. The marmots (woodchucks, gophers, prairie-dogs, etc.) are nearly related to the tree squirrel, but terrestrial and more or less burrowing in habit, adapted to live in open country and in temperate or arctic climates. The beavers are more distantly related; they are a small group, of highly specialized habits, large-brained and intelligent for rodents. There are only two living species, the European and American beaver. As is well known, they live in colonies, in artificial lakes which they construct by damming streams with logs, brush and mud, each family making a nest or burrow in or beside the shallow waters of the pond, accessible by an underwater entrance. Both species have been hunted almost to extinction for their fur. A large extinct relative of the beaver, Castoroides, lived in North America during the Glacial Epoch, equaling the black bear in size, but nothing is known of its habits, except that its remains are mostly found in ancient swamps and pond bottoms. During the Tertiary Period small animals related to the Beaver (Steneofiber) were common both in Europe and North America, but their habits were like those of the modern prairie dogs. They constructed elaborate winding, corkscrewlike burrows, and the remains of these burrows, filled in by sand and petrified, are known in the West as "Devil's Corkscrews." It is not easy to see how the peculiar habits of the aquatic beavers could have evolved from those of these burrowing ancestors, but they were, perhaps, a side branch, not directly ancestral.

The pocket gophers and pocket mice of North America are intermediate between the squirrel and rat groups of rodents. They get their name from the large cheek-pockets in which they carry food and transport earth from their burrows. The pocket gophers are completely subterranean, equalling the mole in their digging powers, but living on vegetable food. The pocket mice are terrestrial, and some of them active leapers. The jerboas and their relatives are also specialized for leaping rather than running, but are more nearly related to the rats and porcupines than to the squirrels. They inhabit the northern continents and Africa, mostly living in open plains or desert regions.

The most abundant of the rodent groups are the rats and mice and their relatives. These are found all over the world; a few have even penetrated to Australia, and to various oceanic islands which few or none of the other mammals have contrived to reach. They are nearly all of small size, living upon all kinds of plant food, and often more or less omnivorous, adapting themselves very readily to varying conditions of life and endowed with great fecundity. Their depredations upon crops, upon stored grain, upon household supplies, the damage they do by girdling trees for the edible inner bark, cause enormous losses in various fields of human activity, so that they rank with noxious insects in their economic importance. Birds of prey are their chief natural enemies, more efficient in general than any artificial check on their increase.

The porcupine group of rodents are represented by two or three large, spiny-coated species in the northern continents, but their headquarters are in South America, where they include the cavies and chinchillas, viscachas, agoutis, capybaras, and many others, of which the largest, the capybara, reaches the size of a pig. Quite a number of this group of rodents inhabit Africa, and during the Tertiary Period they were the only rodents in South America, and one extinct genus is estimated to have attained the size of an ox, much beyond that of any other rodent.

The last group of rodents are the hares, rabbits and picas, worldwide in distribution, but most familiar and abundant in the north temperate and sub-arctic regions. In Australia and New Zealand they have been introduced by the white settlers, and have thriven and multiplied exceedingly, so as to be a serious pest in the absence of their natural enemies. Their limbs and feet are more specialized for speed than in most rodents, altho the rabbitlike cavies and chinchillas of South America show a corresponding adaptation.

Under the name of Hoofed Mammals, or Ungulata, are commonly grouped together several orders of mammals which are not in fact nearly related to each other. They are all herbivorous, adapted to terrestrial life, using the feet only for walking or running, and in all of them the claws have been thickened and broadened into hoofs, serving for support, but useless for grasping or climbing. So far as can be judged, they are derived from several stocks of primitive clawed ancestors, in each of which the hoofs have been independently evolved in adaptation to similar habits of life. The horses, tapirs and rhinoceroses are derived from one primitive stock, the pigs and ruminants from another, the elephants from a third, while there are several extinct races of hoofed mammals derived from still other primitive stocks. The Ungulates are all medium to large-sized mammals, many of them gigantic, none of them very small. Their brains are mostly of high type, and in intelligence they rank with the Carnivora, decidedly above any of the orders that we have considered, except the Cetacea, and exceeded only by the higher Primates (Monkeys, Apes and Men). The two most important groups are the Perissodactyls, or Odd-Toed, and Artiodactyls, or Even-Toed Hoofed Mammals. In the former the number of toes, in the hind foot at least, is three or one, the axis of symmetry passing through the middle digit. In the latter the number of toes is four or two, the axis of symmetry passing between the two middle digits. There are numerous other points of difference in the structure of teeth, skeleton and soft anatomy, which show that these two groups are distinct; that while animals so different as the horse and rhinoceros are derived from a common ancestral stock, the tapir and the pig, or the rhinoceros and the hippopotamus, are derived from different primitive stocks of placental mammals. These relationships are fully confirmed by what is known of the geological history of the various races of ungulates. Owing to their large size and comparative abundance, fossil hoofed mammals are more common and better known than any of the other groups, and the geological history and evolution of many of the ungulate races is quite fully known.

"The Horse," wrote the small boy in his essay, "is a square animal with a leg at each corner," a definition that might perhaps be improved upon. But in fact the horse needs no definition to bring it before the eye of man, woman or child. Its graceful proportions, compact, well-knit body, long head and arched neck, its flowing mane and tail, its slender limbs and one-toed feet tipped each by a broad, solid hoof—these are the ideal proportions of the swift-running hoofed mammal, designed to cover long distances at a high rate of speed.

True horses are practically unknown in a wild state, the so-called wild horses being, for the most part, descended from animals which have escaped from domestication. The Przewalsky horse of the deserts of Central Asia is, however, believed to be a truly wild species. The closely related asses and zebras occur in the wild state in Western Asia and in Africa; they differ from the horse chiefly in size and color pattern, and all are included in the genus "Equus." In a broad way all of them may be called horses.

The structure of the feet and teeth in the horse, using the word in this broader sense, is unique among modern animals. The foot has but a single toe, corresponding to the middle or third digit of a man, but the second and fourth digits are represented by small rudiments, "splint-bones," which lie closely pressed against the back of the cannon-bone (corresponding to the third metacarpal bone of the palm in the human hand or the third metatarsal bone of the instep in the foot). These rudiments are all that is left of the second and fourth toes; of the first and fifth there is no trace at all.

The cheek teeth are equally peculiar. They are long, square columns, growing at the base and pushing up from the jaw as they wear off at the surface in grinding the food. They are composed of enamel, dentine and cement; the enamel, which forms the covering of the usual type of mammal tooth, is infolded into a complicated pattern, its worn edges supported on one side by the dentine which underlies the enamel in the normal mammal tooth and on the other by cement, a special substance slightly softer than the dentine, deposited on what is at first the outer side of the enamel before the tooth pushes up through the gum. By this means the grinding surface of the tooth at any stage of wear is composed of a complex pattern of hard enamel ridges braced on either side by the somewhat softer dentine and cement. This forms a most efficient instrument for grinding and triturating the hard, dry grasses which are the natural food of the horse.

In the successive formations of the Tertiary Period in the Great Plains region of the Western United States have been found a series of evolutionary stages leading up to the modern horse from small ancestors no larger than a cat, with four toes on the fore foot and three on the hind foot, and with grinding teeth of the primitive "bunodont" type, such as are still retained by man and many other mammals. These little "four-toed horses" are scarcely distinguishable from the contemporary ancestors of tapirs and rhinoceroses. The successive stages of the divergent lines of evolution which led up into the three widely different modern types have been found in the successive formations of the American Tertiary. About a dozen successive stages are known, nearly all from complete fossil skeletons, besides numerous incomplete ones, which illustrate the gradual transition from the little "Four-Toed Horse" to his modern descendant. In the Eocene the ancestors of the horse had four complete toes in the fore foot, three in the hind foot, all resting on the ground. In the Oligocene they had but three complete toes on fore or hind foot, all resting on the ground, but the side toes are slender and the middle digit larger. The outside toe of their Eocene ancestors is represented by a rudiment or "splint." In the Miocence the central toe is more enlarged, and the side toes are very slender and no longer touch the ground, but are like the "dew-claws" of a dog or deer. In the Pliocene the side toes are still more slender and the bones of the middle digit have more clearly the proportions of those of a horse; and in the Old World it is seen that there were already one-toed horses, in which the dew-claws had disappeared

In the Pleistocene Epoch all horses were one-toed like those of to-day, and at that time there were species of wild horse in Europe, Asia, Africa, North and South America. Since that time the geographic range of horses has been much restricted. They disappeared wholly from the New World, to be reintroduced by European settlers in North and South America. They are no longer found in a wild state in Europe, nor in most parts of Asia, and the zebras and wild asses are rapidly disappearing. The domesticated breeds, which are believed to be crosses of Asiatic, North African and perhaps native European wild horses, have been introduced everywhere that civilized man has made his home; and feral races, escaped from domestication, have re-peopled the high plains of both Americas.

The evolution of the Horse is to be regarded as an adaptation to changing conditions of climate and geography which favored more and more the development of swift-running types in open grassy plains. At the beginning of the Tertiary Period the plains of Western America lay near to sea-level, had a moist sub-tropical climate, and were heavily forest-clad. Throughout this period they were being slowly elevated above sea-level, the climate was becoming colder and more arid, and the forests were disappearing, to be replaced by extensive grassy plains. Of the original population of animals some retreated southward with the changing climate, and their descendants are to-day to be found in the tropical forests. Some became extinct, and are known to us only from their fossil remains. Some, like the horses, were able to adapt themselves to the changing conditions, and their descendants, much changed in form and habit, still survive. Hand in hand with the changes in foot structure adapting them to swift running, went changes in the teeth adapting them to feed upon the hard, dry upland grasses. The steady increase in size is a common feature in many races of animals, especially of ungulates.

The Tapirs afford an example of a race which has followed the climate southward instead of altering its habits and structure. Tapirs to-day inhabit the forests of tropical America and the Malayan peninsula. They retain the primitive construction of the feet, four toes in the fore foot, three in the hind foot, and their teeth are not greatly changed from the primitive type of the Eocene ancestors of horses, tapirs and rhinoceroses. Except for increased size and bulk and the development of a short flexible proboscis they have changed but little. During the early part of the Tertiary Period tapirs inhabited all the northern continents, but their range was gradually restricted further and further to the south.

The history of the Rhinoceroses is much the same as of the Tapirs. In the early Tertiary their ancestors had four toes on the front foot, three on the hind foot, and primitive short-crowned "bunodont" teeth. Like the early horses, these ancestral rhinoceroses lost the outer digit in the forefoot, and began to lengthen out the crowns of the teeth, making them more efficient grinders. But they got no further than these first steps, and then, like the Tapirs, they followed the changing climate southward, in preference to adapting themselves to new conditions of life. Rhinoceroses were common in Europe, Northern Asia and North America as far north as Canada during the early and middle Tertiary, but by the end of the Tertiary they had disappeared from the northern regions, except for a few survivors in Europe and Asia; and to-day they are found only in the tropical regions of the Old World, in India and some of the East Indian islands, in Africa as far south as Cape Colony. In the New World they have become wholly extinct.

Other races of the early Perissodactyls have become entirely extinct. Such were the Titanotheres of Tertiary North America, huge, massive rhinoceroses-like animals with humped back like the bison, and paired bony horns at the front of the solidly built skull; the Palæotheres of the European Tertiary, smaller, hornless, tapir-like in size and proportions, but with only three front toes; and most peculiar of all the Chalicotheres, an odd combination of horse and rhinoceros in proportions, but with the hoofs reconverted into large, powerful claws, used probably to dig around trees and uproot them in order to feed upon their foliage.

In reviewing the historical development of the Perissodactyls it must be deemed an order that has passed its prime and is tending toward extinction. It was represented during the Tertiary Period by a great number and variety of members, both small and large. Its living representatives are few in number, of large size, scattered, widely diverse in form and habits, and, except for the horses, confined to tropical regions. Even the horses, the most successful in adapting themselves to modern conditions of life, do not appear to maintain themselves in competition with their numerous and varied rivals of the ruminant group, which are by far the most abundant among modern hoofed mammals.

The order Artiodactyla includes two principal groups, first the non-ruminants (pigs, peccaries and hippopotami), with the primitive bunodont type of teeth and with four separate digits in each foot, altho the side toes are sometimes much reduced; second, the ruminants (camels, deer, antelopes, sheep and cattle), in which the cheek teeth are adapted for grinding, altho with a wholly different pattern from the grinders of horses or rhinoceroses, and there are only two complete digits on each foot, the metapodials of which are fused into a single "cannon bone," altho the toes remain separate, and the side toes are rudimentary "dew-claws" or altogether absent. The first group retain more nearly the ancestral characters of teeth and feet, and have survived owing to certain unusual habits of life or special means of defense which have protected them against competition. The second group is the progressive and dominant group of herbivorous mammals.

The pigs of the Old World and the Peccaries of the New are provided with bristly hair, thick skin, and very efficient canine tusks. They are compact-bodied, bold and active fighters, dangerous adversaries whom their carnivorous enemies or herbivorous rivals may well hesitate to attack. Nevertheless, their range and numbers have been much decreased since the Middle Tertiary. Several large kinds of peccary inhabited North America as far north at least as the Canadian border up to the Pleistocene Epoch; there is now but a single genus which ranges from Southern Texas to Brazil. In Europe there were also a number of true pigs, some of large size, during the later Tertiary; the wild boar is the only surviving type in temperate regions, but in tropical Africa and the East Indies there are several others, the Wart-Hog, Red River Hog, Babirussa and a number of species of pigs. The pigs, like the tapirs and rhinoceroses, have followed the tropical forest and climate southward in its gradual disappearance from the temperate zone.

The Hippopotamus is among the largest of living quadrupeds, thick-skinned, almost hairless, its broad, short feet with four toes of nearly equal size, its huge jaws and long, heavy tusks adapted to root in the mud of river bottoms. Chiefly aquatic in its habits, it can remain under water for some time before coming up to breathe. It is found to-day only in the rivers of Central Africa, but had formerly a much wider range, inhabiting Madagascar and Southern Asia and ranging northward into Europe.

Nine-tenths of the hoofed animals belong to the Ruminants, a section of the Artiodactyls. They are distinguished especially by the peculiar complexity of the stomach which enables them to chew the cud. It is divided into four chambers, the first and largest, or paunch, serving to contain the hastily swallowed food, which is later returned to the mouth, thoroly masticated at leisure, and passes to the other divisions of the stomach for digestion. The advantage of this habit of "chewing the cud" to an herbivorous animal whose food requires thoro chewing is very considerable. Food can be obtained hastily where rich and plentiful, while the necessary mastication can be continued while en route from the feeding grounds or during rest, or deferred till a place of safety is reached. The limbs and feet of ruminants are highly specialized both for speed and endurance, almost if not quite as much as in the horse, while the "divided hoof"—really two separate hoofs closely paired—gives them a better footing on rough or irregular ground.

Among living ruminants the camels and llamas stand apart as a primitive and peculiar race, specialized for desert life. The long, loose-jointed limbs and padded feet lack the speed adaptation of the higher races, but are well fitted to traverse the loose desert sand; the stomach is less complex but peculiarly specialized to carry a supply of water which enables the animal to go without drinking for several days at a time. Altho the camels are now found only in the Central Asian and North African deserts and the llamas in the arid regions of South America, they were during the Tertiary period a peculiarly North American family, and the evolution of the race has been traced almost as completely as the evolution of the horse, back to little ancestors no larger than a cat, with four separate digits on each foot. They disappeared from North America before the appearance of civilized man, like the native American horses, and the preservation of camels in the Old World is perhaps, like the preservation of the Asiatic Horse, due to their being domesticated by man. It is doubtful whether any truly wild camels exist either in Asia or Africa. If these domesticated races be set aside it will be found that camels and horses have both disappeared from the northern continents, where they were abundant during the Age of Mammals, but are preserved in the outlying southern continents, the peculiarly American camels in South America, the cosmopolitan horses in Southern Africa. Looking at the matter in this way, it may reasonably be supposed that they were driven into the outlying southern regions through their inability to contend with the more perfected ruminants whose center of dispersal was in the great northern land mass. Both camels and llamas have been domesticated by man and used as beasts of burden; the Bactrian or two-humped camel in Central Asia, the dromedary in North Africa; the llama was the only beast of burden in ancient Peru, while the smaller alpaca was kept for its fleece and meat. The wild races of these two species still exist in the high plains of South America under the name of guanaco and vicuña.

Before taking up the typical ruminants, or Pecora, allusion may be made to the chevrotain of the dense forests of the East Indies, and the water-chevrotain of the equally dense forests of West Africa, both regions the refuge of many primitive survivors of the Tertiary fauna. These two genera are grouped together because of the less perfected food-structure and lack of horns, and represent quite nearly the early Tertiary stage in the evolution of the ruminants, as it is found fossil in Europe and North America.

The true ruminants or Pecora are undoubtedly the dominant group of herbivora to-day. They are a group of comparatively recent evolution geologically, and first appear in the Middle Tertiary, developing out of primitive artiodactyls mainly in the Old World. Their center of diffusion was apparently Northern Asia, whence they spread to Europe on one hand, to North America on the other, reaching Africa and South America at a later date, probably toward the end of the

Tertiary period. They include three main sections; first the Giraffes, in which the horns are bony excrescences covered with a skin-pad; second the Deer, in which the horns (antlers) are covered with a skin-pad (the "velvet") only when newly formed, and are shed annually; third, the Antelopes, Sheep and Cattle, in which the horn cones are covered with a heavy, solid and tough true horn, which is permanent during the lifetime of the animal.

The Giraffes may be regarded as the most primitive of these three sections. They are to-day limited to Africa, the giraffe being adapted to the semi-desert plains, where its long neck enables it to feed upon the succulent upper foliage of mimosas and thorny bushes; while its ally, the recently-discovered Okapi, inhabits the deep forests of Central Africa. Fossil giraffes have been found in the late Tertiary of Asia and Southern Europe, and nearly related forms in India (Sivatherium, etc.) were of greater bulk altho not so tall, and had the horns much larger and more branched.

The deer are especially adapted to forest life, the teeth short crowned and suited for browsing. They inhabit all the forest regions of Europe, Asia, North Africa and the two Americas, but have been prevented from reaching the Ethiopian region by the wide stretch of the Saharan desert and the arid mountainous country to the east of it. The largest and most progressive of the deer are found, as one might expect, in the Arctic and cold temperate zones of the North, the wapiti and red deer, the reindeer and caribou, the moose and (European) elk being the highest development of the family. The smallest and most primitive members live in Southern Europe, in Southeastern Asia, the East Indies and in Central and South America. The earliest deer were of small size, at first hornless, like the modern musk deer of the Himalayas and water-deer of China, or the fawn of any of the larger deer; then with a single spike, like the Central American "brockets," or the second year of the larger deer (to which the term brocket originally belonged); then with two, three or more tines, all the stages being paralleled both by the adults of different species of modern deer and by the annual changes in the young of the larger northern deer.

The antelopes, sheep and cattle are primarily adapted to living on open plains. The teeth are mostly long-crowned, and in many of them the grinding edges of the enamel are braced by a heavy deposit of cement, as in the horses. They are thus suited to feed upon the hard, dry plains grasses, which require very thoro chewing before their nutrition becomes available. "Antelopes" is a broad term that covers all the various races except two—the sheep and goats, and the cattle—which on account of the domestication by man are of especial importance and have received especial names. From the zoological point of view they are not more different from antelopes than the different races of antelopes are from each other. But they may fairly be considered as the highest and most progressive of the various antelope groups.

The antelopes are to-day most abundant and varied in Africa. In Europe and Asia, where they were numerous during the late Tertiary, they have been mostly displaced by the sheep and oxen, but are still found in large numbers in India, in Arabia and Syria, and a few in the more central parts of Asia. Except for one or two little known extinct species, they do not appear ever to have reached the New World; the so-called Antelope (Prong-horn) of the Western plains is a solitary survivor of a distinct race intermediate between deer and antelopes in its affinities and especially characteristic of North America.

The smallest antelope is the little Madoqua or Pigmy-antelope of East Africa, no larger than a hare. Not much larger are the Duikerboks (Cephalophus) of South and East Africa, so called from the dexterity and quickness with which they "duck" or dive into the tall grass or bushes to escape from their pursuers. In these the horns are small, straight spikes. The gazelles, with longer, ringed horns, delicate head with large, soft eyes, slender neck and long limbs, are generally admitted to be the most graceful of the hoofed quadrupeds and unsurpassed in speed. In the larger antelopes the horns are either ringed or spirally twisted, mostly projecting upward with a slight backward curve, but in the gnu they are depressed on the side of the head, as in the sheep. Some of the larger antelopes, such as the African eland or Indian nilghai, have nearly the size and proportions of domestic cattle.

The goats, sheep and cattle are the latest of the antelope groups to appear in geological history, and the wild species are to-day predominantly Asiatic in their distribution. The cattle, however, are widely distributed throughout Africa, India and the East India islands, and in North America are represented by the bison and musk-ox. The big-horn and mountain goat of northwestern North America are the only New World representatives of the sheep and goats; a single species of wild sheep is found in North Africa; otherwise they are all Palæarctic, a few, such as the Ibex and Chamois, inhabiting the mountainous regions of Europe, most of them the highlands of Asia. While the cattle are especially plains and lowland types, the sheep and goats are preëminently mountain dwellers, active climbers, sure-footed, and able to endure severe cold. The domesticated species of cattle, sheep and goats are of enormous economic importance, and have contributed very largely to shaping the development of Old World civilization.

Besides the ancestors of the modern pigs and ruminants, there were various races of this order of hoofed animals that have not survived.

The Elotheres were large animals with huge skulls, cheek teeth like those of pigs, front teeth more like carnivorous mammals, feet strictly two-toed as in camels and ruminants, but the metapodials not united into a cannon-bone. They inhabited the northern continents in the middle part of the Tertiary period. The skull of the largest of them, "Dinohyus," is over three feet long, the animal as large as the hippopotamus but with much longer legs and short, massive body proportioned more like the bison. The Oreodonts, very abundant in North America at the same time, have been called "ruminating hogs," as they combined the four-toed feet of the pigs with a ruminating type of teeth. They must have resembled peccaries in appearance and habits, but with shorter snout. The contemporary Anoplotheres took the place of the Oreodonts in the Old World; the Anthracotheres, pig-like in proportions, with teeth partly intermediate between those of pigs and ruminants, are regarded as more or less directly ancestral to the hippopotamus.

The Elephants are the most gigantic of living quadrupeds and the most singular in appearance. The elongation of the snout into a long, flexible trunk, serving much the same purposes as the hands in man, sets them apart from all other ungulates as, in this respect at least, a higher mechanical adaptation. For there can be no doubt that the development of the hand into an effective organ of prehension, released from the functions of locomotion, has played an important part in the evolution of intelligent life in man; and in the elephant we see an entirely different organ serving the same purpose almost as effectively. To find the elephant ranking as the most intelligent of hoofed animals, then, is what might be expected. The limbs are long, straight and massive, the feet short, rounded, heavily padded, with five small hoofs on each. This construction is best adapted to support the gigantic weight of the body—five to fifteen thousand pounds—and all very large land animals approach it more or less nearly.

The teeth are very highly specialized. One pair of upper incisors is enlarged and lengthened into tusks; all the other front teeth have disappeared. Of the cheek teeth only the molars remain, and these are high crowned, composed of alternating transverse plates of enamel, dentine and cement. The three molars come into use one after another, dropping out as they wear down to the roots, and in a fully adult elephant only one grinding tooth is left on each side of upper or lower jaw. Four grinders and two tusks constitute the entire adult dentition, and even the tusks are absent in the female. The skull and jaws are extremely short, and large in proportion, giving room for the attachment of the powerful muscles necessary to wield the trunk and tusks and grind the food—leaves, twigs, fruits and forest grasses. Unlike other long-limbed animals (excepting man) the neck is very short, as the trunk makes it unnecessary for the head to reach the ground.

The average height of elephants is from eight to ten feet, but the African species at least, sometimes reaches twelve feet in height. Jumbo was eleven feet high, his weight six and a half tons. The Indian species is more massive, but not so tall as the African one; its forehead is higher and grinders larger, with more numerous and closely set plates; the tusks are smaller and often absent in males as well as females.

Elephants have been tamed since the days of the ancients, both the Indian and African species. Those brought by Hannibal from Carthage must have been African elephants; but the Greeks and Romans were more familiar with the Indian species.

The two modern species of elephants are the last survivors of a race widely distributed in prehistoric times. The mammoths were simply a species of elephant; the mastodons were a nearly related genus, but with shorter crowned and more numerous teeth, and other primitive characters. These during the Pleistocene epoch ranged over all the northern continents. Mammoth remains have been found in all parts of Europe and in Asia northward to the Liakhof Islands in the Arctic Ocean, where vast quantities of their tusks and bones are preserved in the frozen soil. In America the mammoths of different species ranged from Siberia to Mexico. The Mastodons were of even wider range, penetrating into South America as far as the Argentine plains. The Arctic species of elephants were covered with a shaggy coat of reddish brown wool, mingled with longer black hairs. In Siberia and Alaska carcasses of these animals more or less complete have been found preserved in the frozen soil. The southern mammoths were more probably naked-skinned like the modern elephants, which they somewhat exceeded in height and bulk. A skeleton in the Paris Museum is slightly over three meters (thirteen feet) in height. The mastodons were also partly covered with hair. The tusks in some of these mammoths and mastodons were of enormous size, curling inward and crossing at the tips. Some of these fossil tusks measure thirteen feet in length and nine inches in thickness. Like the tusks of modern elephants they are composed of ivory or dentine only, the enamel being lacking.

During the latter half of the Tertiary Period Primitive Mastodons (Gomphotherium) inhabited Europe, Asia and North America. They were much smaller than the Pleistocene Mastodons and Elephants, with tusks in both upper and lower jaws, and shorter limbs, longer skull, and much shorter trunk. The lower tusks are short and straight, or in the earliest forms curving slightly downward, and with a strip of enamel on the face of the tusk. In a related genus, "Dinotherium," the upper tusks were absent, the lower ones large and curving downward; and in this animal the grinding teeth were more numerous, five on each side of each jaw, while the "Gomphotherium," like the true Mastodon, had but three.

A complete series of intermediate stages between the Primitive Mastodons and the modern elephants is found in the successive formations of the later Tertiary in Europe and Asia. The early history of the Proboscideans was unknown until very recently, when the explorations in the Fayûm district of Egypt disclosed an early Tertiary fauna which included, among other large quadrupeds new to science, the early stages in the evolution of mastodons and elephants. These carried back the ancestry of the elephant to a small animal (Mœritherium) about as large as a cow, with a nearly complete series of teeth, short crowned grinders, one pair of incisors, enlarged and somewhat like the gnawing teeth of rodents, with long head, no trunk, and short limbs. Palæomastodon was intermediate between this type and the primitive mastodons.

Reference has been made to the various extinct relatives of the Perissodactyls, Artiodactyls and Proboscideans. But during the Age of Mammals there were a number of groups of hoofed mammals not related to any of the living orders, and some of remarkable proportions and gigantic size. In North America, during the Eocene epoch, lived the "Uintatherium" or "Dinoceras," a huge creature larger than an Indian rhinoceros, with elephantine limbs and feet, its head armed with three pairs of bony horns and great, saber-like upper tusks. In Africa, about the same time or a little later, lived the "Arsinoitherium," equally huge and elephantine in limbs and feet, and with a pair of great, sharp horns at the front of the skull. South America, during the long period that it remained an island continent, developed a great variety of hoofed mammals, unrelated to those of the northern continents, but sometimes paralleling them to a remarkable extent. In the South American Eocene is found a great elephantine quadruped, the "Pyrotherium," singularly like the ancestral mastodons in many respects, but probably not closely related to them. In the Miocene lived another huge beast, the "Astrapotherium," again with elephantine limbs and feet, and apparently provided with a shorter trunk; but with tusks like those of pigs and peccaries only of larger size, and with grinding teeth that bear a general resemblance to those of the rhinoceros. At the same time lived smaller animals, the "Nesodons," proportioned somewhat on the lines of a small hornless rhinoceros, and little Typotheres, rabbit or coney-like in size and proportions, but in fact related to the Nesodons.

The most interesting members of this Miocene fauna of South America were the Litopterna, some of which paralleled the horses in their foot-structure with extraordinary closeness, altho not at all horse-like in the skull or teeth. The side-toes were reduced to "dew-claws" as in the later three-toed horses, and finally disappeared, leaving only the central toe with a rudimentary nodule of bone to represent each side toe, like the splint of the modern horse. The form of the foot bones throughout becomes singularly like that of the true horses. Other Litopterna retained three well-developed toes like the rhinoceroses, but their limbs had rather the shambling build of the camel than the more compact proportions of rhinoceros or tapir. At the end of the Tertiary still other gigantic ungulates developed in South America. The Nesodons gave rise to the huge massive "Toxodon," exceeding a rhinoceros in size; the three-toed Litopterna to the camel-like "Macrauchenia."

All these extinct groups of the Ungulates were evolved in North America, in South America and in Africa during epochs when these regions were cut off from the main center of diffusion of mammals, the great land mass of Northern and Central Asia. The corresponding forms evolved in this larger central region were subject to severer and wider competition, were more advanced, intelligent, active or hardy than the quadrupeds evolved in the smaller isolated areas. Consequently, when these areas were joined to the central land mass, its fauna invaded them and swept out of existence all the competing autochthonic types.

The Manatee and Dugong are the remnants of a group of herbivorous mammals, nearly related to the ancestors of the elephants. Like the Cetacea, they have adopted an aquatic life, and become more or less fish-like in form, losing the hind limbs, developing the tail into a swimming organ, and the fore limbs into fin-like paddles, and entirely losing the hair. Unlike cetaceans they are sluggish, slow-moving bottom feeders, living on the aquatic vegetation of tidal rivers or upon sea-weeds. The Dugong of the Red Sea and East Indies, and the Manatee of the Atlantic coasts are the only survivors. A larger form, Steller's Sea Cow, inhabited some of the Aleutian Islands until 1758; and in the Tertiary formations of Europe and North Africa various ancestral stages have been discovered. The name Sirenia may seem singularly inappropriate for such peculiarly ugly animals, yet it is not unlikely that some of the older reports of mermaids were based upon the dugong, owing to the custom of the parent holding the young to her breast with her flippers, the round heads of both being raised out of the water.

The "Carnivora" are the Beasts of Prey, specially adapted for flesh-eating and predacious habits. For the most part they are exceptionally active, strong and restless, of high intelligence and perfect bodily mechanism. In so far as perfection consists in mechanical adaptation to an active and varied life, the carnivora may indeed be regarded as the highest of living animals. Man indeed, in respect of his mental powers, stands far above the rest of creation, but as an all-round athlete he must yield the palm to the Carnivores.

Besides the land carnivora this order includes the Seals and Walruses, adapted to a marine life, and again partially assuming a fish-like form, although they have retained their furry covering, and in the absence of a heavy tail the hind limbs have been converted into a propelling organ, instead of disappearing as they have done in cetaceans or sirenians. The fore-limbs are converted into flippers, and the teeth mimic those of the early toothed whales in their adaptation to fish-eating. But seals and walruses are not as helpless on land as are dolphins or whales; their adaptation to marine life is not so complete. The great "rookeries" in which seals congregate for breeding purposes, and the long migrations which they undertake each season, are remarkable features of their life.

The terrestrial carnivora are more numerous and familiar. Their teeth are specialized for seizing their prey and for cutting flesh. The canine teeth are large, sharp and strong, one pair of cheek teeth is enlarged and converted into stout shearing blades which act like a pair of scissors; these are termed carnassials, and the cheek teeth in front of them are usually of cutting type, while the molars behind are used for crushing or are entirely absent. The feet have either four or five digits, the claws usually sharp and sometimes retractile, so that they can be drawn back out of the way while walking and extended only in seizing their prey. They walk either upon the entire sole of the foot or upon the under surface of the toes, the sole or palm being held free of the ground; but never upon the tips of the toes, as do the hoofed animals. Most of the carnivora are good climbers; some live mostly or altogether in trees. All of them are of high intelligence and keen perceptions, the senses of sight, smell and hearing very highly developed. They are divided usually into seven families:

1. "Canidæ"—Dogs, wolves, foxes and jackals. Partly omnivorous, adapted to swift running and very often hunting in packs. Cosmopolitan.

2. "Procyonidæ"—Raccoons, omnivorous and arboreal. Found only in the New World.

3. "Ursidæ"—Bears, omnivorous, terrestrial, and all of large size. Cosmopolitan except Australian region.

4. "Mustelidæ"—Weasels, martens, skunks, badgers and otters. Mostly predacious and of small or medium size, found everywhere except in the Australian region.

5. "Viverridæ"—Civets, mongooses, etc. Mostly predacious and of small or medium size, confined to the Old World exclusive of Australasia. The few species of Carnivora in Madagascar all belong to this family.

6. "Hyænidæ."—Hyenas. Predacious and of large size, found only in Africa and Southern Asia.

7. "Felidæ."—The cat family, including the lion, tiger, and various smaller cats. Strictly predacious, large or of medium size. Cosmopolitan except Australasia.

The dog family are more adapted for speed than any other carnivora, and the larger species often hunt in packs and run down their prey in the open. They are equally expert in tracking their prey, the sense of smell being very highly developed. Unlike most carnivora, the claws are blunt and are used only for locomotion; and they are quite unable to climb trees. Their range extends from the Arctic to the equator regions and southward to Patagonia and the Falkland Islands. The true wolves and foxes are mostly found in the northern continents; the jackals are Oriental and African; while South American canids belong to a somewhat primitive group known as dog-foxes. The dingo is the only member of the carnivora which has entered Australia, but whether introduced by primitive man or naturally is not certainly proven. All of the family are much alike in structure, differing mainly in size, color and habits. They are all included in the genus Canis except four of five species inhabiting India, Africa and South America.

The Raccoons of the New World are more or less related to the dogs, but aboreal, forest-living, nocturnal and omnivorous. The "coon" has a well-deserved reputation for cleverness and cunning, qualities shared by the less known members of the family, the coati, caxomistle and kinkajou of the Central and South American forests. The last-named is the most strictly aboreal of the carnivora; its tail prehensile like the monkeys, which it resembles in habits and food.

The Bears are the largest of the carnivora. They are omnivorous, or rather frugivorous, feeding mostly upon roots and berries. They are long limbed, almost tailless, walk upon the sole of the foot, and the large, sharp claws are used in digging out roots, bulbs, insects and honey, of which last they are extremely fond. Their main subsistence in the summer is upon berries. In the north they hibernate through the winter season of scarcity and cold, coming out in the spring hungry and ravenous, ready to seize and devour anything they can find. In general, however, bears are easy-going, good-natured animals, rarely atacking man, and generally doing their best to escape when attacked, dangerous only when cornered or wounded, when hungry, or when their cubs are endangered. Perhaps an exception should be made of the polar bear, which is entirely carnivorous, living upon seals, fish, or occasional land animals, and correspondingly savage in temperament.

The bears are chiefly a northern race, but are found in India and the East Indies, in Algeria and in the Andes mountains. The largest species are the huge Kadiak bears of Alaska; the polar bear is almost as large.

The weasel and civet families are mostly small but bloodthirsty and fierce beasts of prey, with long tails, rather short legs, and usually slender "vermiform" bodies. Most of them are terrestrial or partly aboreal, but the weasel family includes also fossorial (badgers) and semi-aquatic types (otters). The largest member of the Mustelidæ is the Glutton or Wolverene of the boreal zone in both Old and New World. The Old World Viverridæ are chiefly found in the Oriental region and in Africa; two or three have reached Madagascar, where they are the only carnivorous animals. The Mustelidæ, on the other hand, are more northern in their distribution, altho found in all the great continents except Australia.

The Hyenas are large Old World carnivores related to the civets, but living in more open country and preying upon larger game. They are commonly called carrion-eaters, but are in fact more like the dogs, tracking and running down live prey or feeding upon carcasses, pretty much as opportunity offers. They are, however, gross and indiscriminate feeders, contrasting in their manner of eating with the more dainty habits of the cats; and the teeth are massive, heavy, usually much worn on the edges. They now inhabit India, Southwestern Asia and Africa, but formerly ranged all over the northern parts of the Old World, never having reached the New. Teeth and bones of hyenas and their prey are the most abundant fossil remains in the "bone-caves" of England and Northern Europe.

The Cats are the most strictly predacious group of carnivora. They are especially distinguished by the retractile claws—but the claws are slightly retractile in some of the Viverrids—and the teeth are sharper, the shearing action of the carnassials more perfect, the crushing teeth more reduced than in any of the other families. The limbs, especially the fore-limbs, are very flexible and powerful, and they afford perhaps the finest mechanical adaptations for combined strength and agility to be found in the whole animal kingdom. Altho capable of great speed for a short spurt, they are not able to maintain it over long distances; they never run down their prey, but track or lie in wait for it and spring upon it unawares. If they fail to overtake it in the first few bounds they abandon the chase. Cats are all dainty eaters, and among the thousands of skulls in large museum collections it is rare to find one with the teeth much worn, except among the desert species, which must needs encounter considerable loose sand with the food. It is not true, however, that they will not devour an animal which they have not themselves killed.

The largest cats are the lion and tiger, the one inhabiting Africa and Southwestern Asia, the other India and Eastern Asia. The lion is especially an inhabitant of desert or arid countries, and his color matches his surroundings; the brilliant vertical stripes of the tiger are said to be equally effective for concealment in the deep jungles and forests of Southeastern Asia. Both are mainly nocturnal in their habits, as are all the cats.

In the New World, the puma and jaguar correspond to the Old World lion and tiger, but are of smaller size, not exceeding the leopards of the Old World. The lynxes or bob-tailed cats are especially boreal in range, inhabiting the arctic and cold-temperate regions of the northern continents. Various other smaller cats range down to the size of the domestic species, inhabiting all the continents except Australia.

During the latter part of the Tertiary Period lived various carnivora, ancestral or related to the modern kinds. Perhaps the largest of them are the Amphicyons, related to the dogs but equaling the largest bears in size, and apparently similar to them in habits. Unlike bears, they were provided with extremely long and heavy tails, exceeding those of the great cats, while the limbs were rather short.

But the most remarkable of the extinct carnivora are the Saber-toothed Tigers or "Machaerodonts," related to the true cats, and similar to them in general proportions and habits, but with the upper canine enlarged into a great compressed fang, slightly curved and with sharp, serrate edges. The jaws were peculiarly loose-hung and could be opened wide enough to allow full play for the action of the tusks, and powerful muscles at the back of the skull enabled the animal to drive them down with tremendous force into the body of an enemy. The legs were short, the muscles exceptionally heavy and powerful. In all respects the Saber-toothed tigers appear to have been especially adapted to prey upon large, thick-skinned, slow-moving quadrupeds. The largest species equalled a grizzly bear in size, the smallest were about as large as a lynx.

In the earlier part of the Tertiary Period there were numerous kinds of carnivores, with much smaller brains than the modern kinds and more primitive in various respects. These are grouped in a distinct sub-order, Creodonta. Some of them were ancestral to the various families of modern carnivores; others have left no descendants. In habits and general appearance these extinct races were much like modern beasts of prey, but the various peculiar features of the several modern races are found in different combinations.

The order Primates includes Lemurs, Monkeys, Apes, and to it has been added Man. Cuvier, it is true, has placed Man in a separate order of Mammals, Bimana, but almost all other zoologists, ancient and modern, are agreed in including Genus Homo among the

Primates. This, be it remembered, is a zoological classification, and has no reference to traits of character.

Taken as a whole, this order is preeminently the arboreal group among the Mammalia. Its members are more completely and thoroughly specialized for this mode of life than any other group. The long, slender limbs, flexible joints, opposable thumb, long toes capped with nails instead of claws, the long, powerful and often prehensile tail, are all peculiarly adapted to dwelling among the branches of the forest, as the teeth are to eating the fruits and berries which it affords. The highest primates, however, have departed from the typical habits of the order and become partially or completely terrestrial.

It is probably to the stimulus of arboreal life that the Primates owe the beginnings of that higher intelligence which distinguishes them. Travel among the branches of trees affords more continuous opportunities for the exercise of intelligent choice in determining every successive movement than does the more uniform and safer progression upon the surface of the ground or in the water, or the violent but unvarying exercise of flying. One finds that arboreal animals usually rank high in intelligence, as, for instance, the squirrels among rodents, the raccoons among the carnivora, the tree-shrews among insectivora, the opossums among marsupials. In addition, the opposable thumb gives to the primate especial facility in touching and handling objects, and enables him to obtain readily a more exact and complete knowledge of them.

In their skeleton structure this order has departed less from the primitive mammal type than most others. As has been pointed out, the earliest mammals were probably arboreal, and the primates have retained and perfected their adaptation to this mode of life. The most notable lines of progress are in the shortening of the face and enlargement of the brain.

The living primates are divided into two groups—the more primitive lemurs, and the more progressive monkeys, apes and man. The lemurs are chiefly found in Madagascar, but a few of them inhabit Central Africa, India and the East Indies. They have a rather long face, with less reduction in the number of teeth than the higher groups, and in all except the Tarsier the lower incisors project forward instead of upward. The brain also is decidedly smaller and less complex, and they are very noticeably inferior to monkeys in intelligence and activity. They are in fact the little altered survivors of the ancestral primates of the early Tertiary. Some of these ancestral primates gave rise to the more progressive higher types, while others retreated southward to the fringes of the Asiatic continents, or crossed into Africa, and thence reached Madagascar. In the last-named island they found their most congenial home, free from the rivalry or pursuit of the higher types of mammals, and developed into a remarkably large and varied fauna, the largest and most remarkable of which have very recently become extinct. The modern Malagasy lemurs are all arboreal, small or of moderate size, but in the late Pleistocene, probably just before man gained a foothold on the island, there were large lemurs of terrestrial adaptation, paralleling some of the ungulate mammals in their skull, teeth and skeletons; and others with remarkably short face and large brain, paralleling the higher apes. These last, one may suppose, would in the course of time have evolved into creatures paralleling man himself, had not their evolution been cut short by the irruption of the more progressive races developed upon the great northern land mass, in particular by the invasion of early races of man. It should be pointed out that a higher invading race destroys first those inferior races which come most directly into competition with it, while those among the native races, which are of different adaptation and habits, survive, as they do not interfere with the higher race. Man invaded the Malagasy region probably during the Pleistocence (Glacial) epoch; the monkeys have never reached the island. Hence the highly intelligent ground-lemurs, native to the island, which came in competition with him, became extinct; the less intelligent and smaller tree-lemurs have survived, because they did not interfere with man, and had not to compete with monkeys.

Of the higher or Anthropoid section of the Primates, the South American monkeys are the most primitive. All of them are strictly arboreal, one family, Cebidæ, with prehensile tails and opposable thumbs; the other, Hapalidæ, including only the little marmosets, in which the opposability of the thumb has been lost. The marmosets are squirrel-like in size and habits; the Cebidæ are of larger size but not as large as the Old World monkeys and apes. In all the South American monkeys the nostrils are separated by a broad cartilage, and their apertures look outward. In the Old World monkeys, as in man, the cartilage septum is much reduced, the apertures close together and facing downward.

The Old World monkeys and baboons are united into a single family, but are very various in proportions and appearance. The tail is sometimes long, sometimes short, and many of them are more or less terrestrial, especially the baboons. They inhabit all the tropical parts of the Old World, but except for a species of Macaque that lives on the Rock of Gibraltar, none are found in Europe; nor do they live in Northern Asia north of the Altii Mountains. The Macaques (Macacus) are short-tailed, rather short-faced, Asiatic in range with one species in North Africa and Gibraltar. The Langurs (Semnopithecus) are long-tailed, arboreal monkeys of southern and eastern Asia. The Maugabeys (Cercocebus) are

West African, the Guenous (Cercopithecus) are also African, but more widely distributed. Both genera are long-tailed. The baboons (Cynocephalus) are distinguished by the projecting snout with heavy canine teeth; they are mostly of large size, live in herds, and are more omnivorous and ferocious than any other primates. They are all African or Arabian except one species from Celebes, and inhabit rocky and mountainous districts, living chiefly upon the ground.

The last group of the Primates to be considered are the Anthropoid Apes of the family Simiidæ. These are of large size, of higher intelligence than any other primates, tailless, and with complex finger muscles. They are of arboreal habits, walking when on the ground in a semi-erect position, the long arms reaching the ground but not supporting the main weight of the body, and resting on the back of the fingers instead of the palms as in all lower animals. The skin is partly naked. The jaws, especially in the adult males, are large and projecting. The brain capacity is somewhat less than half that of man, making allowance for the size of the body in different species. The four living types are the Gibbons of Southeastern Asia, the Gorilla and Chimpanzee of the West African forests, and the Orang-Utan of Borneo and Sumatra. The similarity of skeleton between this family and the remains of the Pithecanthropus of Java is very great. On account of this relationship the Anthropoid Apes have been very carefully studied and described, and their appearance, habits and structure are familiar to every one.

Remains of monkeys allied to the modern South American genera have been found in the Miocene formations of Patagonia. In the Miocene of Europe have been found remains of various monkeys and lower apes of the Old World. Both are probably derived from the Eocene lemurs of Europe and North America. So far as the direct ancestry of the higher apes is concerned, the geological record is very incomplete. The most interesting of recent discoveries is the Pithecanthropus of Java, founded upon a part of a skull and a femur which probably (but not certainly) belonged to the same individual, and indicated an animal walking upright, but in cranial capacity intermediate between man and the higher apes. This species, however, according to the latest investigations, was of Pleistocene age, contemporary with fully developed men, so that it cannot be regarded as an ancestor in any genealogical sense.

The theory has been advanced that it is to the lands around the Indian Ocean we should look for the discovery of fossil remains of the primates ancestral to man. These, it will be noted, are not simian. But in this brief review of the evolution and geological history of the lower races of mammals it has been seen that while in the southern continents and around the southern fringes of the great northern land mass are found numerous primitive survivals of ancient races, yet the main theater of the evolution of most races of mammals, their chief diffusion center, has always been the great land mass of the three northern continents, united more or less completely during a large part of the Tertiary Period. West Africa and southeastern Asia, with the East Indian Islands adjoining it, contain many primitive survivals of races whose evolution center was in the Palæarctic region.

In the present writer's opinion the geological evidence of the ancestry of man and the most direct phylogeny of many mammals will be discovered when the Tertiary formations of Central and Eastern Asia are adequately and thoroly searched for remains of fossil vertebrates. At present they are practically unknown. From the observations of pioneer explorers it is very probably inferred that fossiliferous formations of Tertiary age exist in some parts of this immense region. The revealing of the evidence which they should afford of the history of the higher mammals is the task for the scientific explorers of the twentieth century.